

**Water Resources Research Institute of the  
University of North Carolina  
Annual Technical Report  
FY 2011**

# Introduction

During 2011-2012 (Fiscal Year 2011), the Water Resources Research Institute (WRRI) of The University of North Carolina System was responsible for fostering and developing a research, training, and information dissemination program responsive to the water problems of the State and region. To develop its programs, the Institute maintains an aggressive effort to interact and communicate with federal, state, and local water managers. The close contact with water managers is a basis for determining the ever-changing water research priorities.

Research priorities continue to be identified by the WRRI Advisory Committee, composed of representatives of several federal and state agencies, local governments, industries, and non-governmental environmental organizations (NGOs). A technical review committee is also convened on an annual basis to advise WRRI staff on the scientific merit of research proposals submitted for funding. Full-time faculty members from all North Carolina institutions of higher education are eligible to receive grants from WRRI.

The information transfer program continued to focus on disseminating results of sponsored research and providing information on emerging water issues, solutions, and regulations. Results of research are disseminated by publication of technical completion reports, summaries in the WRRI newsletter, publication of summaries on the WRRI website, and presentations by investigators at the WRRI Annual Conference and individual group meetings where appropriate. WRRI continues to be a sponsor of continuing education credits by the NC Board of Examiners of Engineers and Surveyors and the NC Board of Landscape Architects. This allows WRRI to offer Professional Development Hours (PDHs) and contact hours for attendance at the WRRI Annual Conference and other workshops and seminars that WRRI sponsors.

WRRI continues to adapt to changes in the landscape of its home institution, NC State University, by consolidating its operations and maximizing staff efficiencies and outputs. They continue to leverage funds from a variety of sources to expand the reach and impact of research and outreach activities, and grow their involvement in and support of water-related research and outreach across the state.

## Research Program Introduction

During 2011-2012 (Fiscal Year 2011), WRRI continued its regular program of fostering research, training, and information transfer responsive to water issues of the state and region. Results from Institute-supported research efforts are expected to assist local, municipal, state, regional and federal agencies improve their decision-making in the management and stewardship of their water resources. To help it chart and sponsor a research program responsive to the water resource issues and opportunities in North Carolina, WRRI interacts closely with the N.C. Department of Environment and Natural Resources, other agencies, water and power utilities, and an array of research and outreach programs within the UNC system and at private higher educational institutions across North Carolina. A research advisory committee provides input, guidance, and review of the Institute's research priorities on an annual basis. This committee is composed of representatives of several federal and state agencies, local governments, industries, and non-governmental environmental organizations (NGOs).

The results of this process are shared with prospective investigators as part of WRRI's annual call-for-proposals. Proposals that address the annual priorities and meet peer review and other criteria receive preferential consideration for funding. Research priorities, as determined via the above process, are incorporated into our Section 104 Objectives on an annual basis. The proposal solicitation, as in the past, is sent to relevant contacts at colleges and universities across North Carolina to apprise them of the opportunity to submit proposals. The call for proposals is also sent to an email distribution list of approximately 180 university faculty across North Carolina. Full-time faculty members from all North Carolina institutions of higher education are eligible to receive grants from WRRI.

The proposals received are sent to a Technical Committee and to external peer reviewers to determine the relevancy, need for the proposed research and relative strength and weaknesses. The Technical Committee convenes on an annual basis to review all comments made by reviewers, advise WRRI staff on the scientific merit of research proposals, and make recommendations regarding proposal funding.

Efforts were made to maintain a consolidated, refined, and focused list of FY11-12 research priorities based on in-depth discussions of the most significant water research needs and priorities for the state of North Carolina. These priorities were included in the annual call for FY 2011-2012, and the projects resulting from this annual call will be funded from March 1, 2012 to February 28, 2013 and will be reported in the next USGS Annual Report. To view priorities related to the projects reported in the following pages, please refer to the 2010 USGS Annual Report for the research priorities that informed those projects.

The FY 2011-2012 research priorities are:

- \* evaluation of alternative water sources (e.g., graywater or harvested rainwater) for differing consumptive uses (e.g., home irrigation), health risks of alternative sources, and potential impacts of alternative water use on overall water supply and demand
- \* quantifying the economic value of water quality
- \* sources, transport, and fate of nutrients and sediments in surface waters, especially, use of data to assess/quantify water quality changes in NC watersheds in which TMDLs and nutrient management plans have been implemented
- \* defining and evaluating in-stream flow needs and aquatic ecosystem function

## Research Program Introduction

- \* groundwater flow and quality (nutrients, agricultural chemicals, metals, etc.), aquifer storage and recovery, and salt water intrusion
- \* understanding, quantifying, and managing risks and uncertainties in public water supplies, in the face of changing population, land use, climate, and regulations
- \* setting rates and financing capital improvements for water utilities, in the face of changing population, land use, climate, and regulations
- \* evaluation of methods for quantifying pollutant removal from stream restoration practices and projects
- \* defining the pros and cons of different stream restoration practices with regard to sediment, N, and P removal and restoration of aquatic habitat, and the appropriate pollutant removal credits for these practices
- \* defining and evaluating realistic management measures that can quantifiably mitigate the effects of impervious cover on aquatic life, in different urban settings and stormwater systems
- \* defining and evaluating realistic management practices that can quantifiably remove from stormwater both nutrients and pathogens/bacteria, and the relative pros and cons of these practices for different contaminants in different urban settings and stormwater systems

# Uncertainty in Surface Water Availability over North Carolina due to climate and land use changes

## Basic Information

<b>Title:</b>	Uncertainty in Surface Water Availability over North Carolina due to climate and land use changes
<b>Project Number:</b>	2011NC158B
<b>Start Date:</b>	3/1/2011
<b>End Date:</b>	2/29/2012
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	NC-2
<b>Research Category:</b>	Climate and Hydrologic Processes
<b>Focus Category:</b>	Water Supply, Hydrology, Water Use
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	Sankarasubramanian Arumugam, Tushar Sinha

## Publications

There are no publications.

**Title:** Uncertainty in Surface Water Availability over North Carolina under climate and land use changes

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### Progress report for the period 03/01/2011 to 03/31/2012

Three specific objectives are encompassed in the proposed study:

**Objective 1:** Quantify the uncertainty on surface water availability under climate change and land use change over the next 10-30 years in the Upper Cape Fear River basin

**Objective 2:** Investigate alternate water allocation strategies for Lake Jordan using the improved estimates of surface water availability over the near-term (10-30 years)

**Objective 3:** Project the changes in monthly streamflow under various climate and land use change scenarios for other watersheds (e.g., Neuse, Catawba and other coastal watersheds) that are experiencing similar pressure on surface water availability due to urbanization and population growth

**Objective 1:** Quantify the uncertainty on surface water availability under climate change and land use change over the next 10-30 years in the Upper Cape Fear River basin

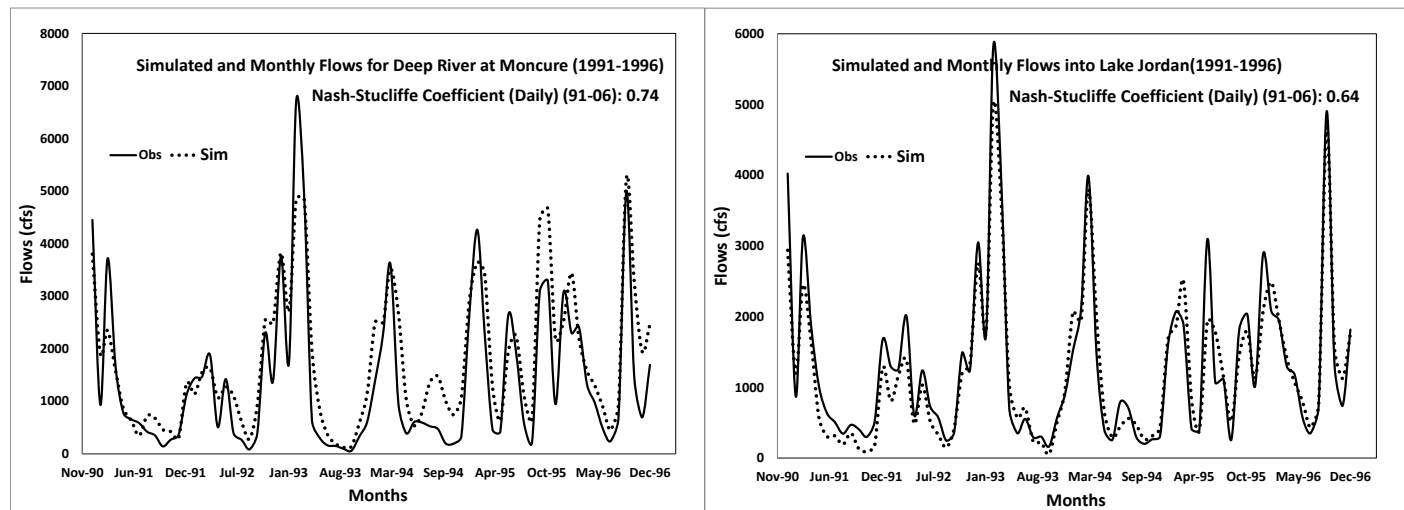


Figure 1: Comparison between observed and modeled flows from SWAT model for Deep river at Moncure (left) and Haw River at Bynum (right). The Nash-Sutcliffe coefficients in predicting daily flows are 0.74 (Deep River) and 0.64 (Haw River).

We have calibrated SWAT model for Haw River at Bynum and Deep River at Moncure (Figure 1). These are the two major sub-basins in upper Cape Fear. We are planning to force these model with multimodel climate runs obtained from Maurer and others global climate database ([http://www.engr.scu.edu/~emaurer/global\\_data/](http://www.engr.scu.edu/~emaurer/global_data/)).

**Objective 2:** Investigate alternate water allocation strategies for Lake Jordan using the improved estimates of surface water availability over the near-term (10-30 years)

We have the reservoir model setup for Lake Jordan and we have tested the model performance with the calibrated flows for Haw River at Bynum. The climate forcings were forced into the SWAT model for two periods – 1980-2010 and 2010-2040. The change in the mean and standard deviation in monthly flows were noted. The differences in the monthly mean and monthly standard deviation were added to the observed mean and observed standard deviation of the observed flows for the period 1980-2010. Based on this perturbed monthly mean and standard deviation with the observed flows, we generated net-inflows from multivariate normal distribution. These net-inflows incorporate the change in flow characteristics that we can expect due to climate change. These net-inflows were forced into the Lake Jordan Model to find out how water allocation between water supply and water quality from Lake Jordan could be allocated without increasing the flood risk. This is investigated by increasing the lake level from 216 to 240, so that the reduced flood storage will not result in increased flood risk (Figure 2). This is an ongoing investigation and we expect to report publish a manuscript based on this work to Journal of Water Resources Planning and Management.

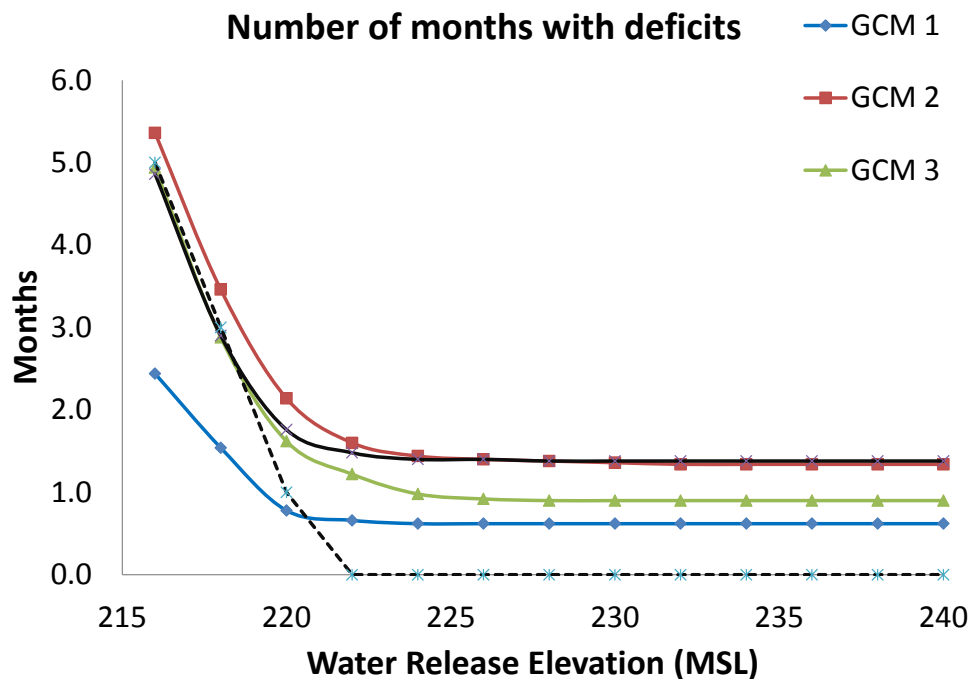


Figure 2: Number of months experiencing deficits in meeting water supply and water quality demand as the bottom of the flood control pool is increased from 216 to 240.

**Objective 3:** Project the changes in monthly streamflow under various climate and land use change scenarios for other watersheds (e.g., Neuse, Catawba and other coastal watersheds) that are experiencing similar pressure on surface water availability due to urbanization and population growth

We expect to complete our analyses on Objectives 1 and 2 by the end of August. Following that, we will try to generalize our findings for other basins.



## The impact of Coal Combustion Products on the quality of water resources in North Carolina

### Basic Information

<b>Title:</b>	The impact of Coal Combustion Products on the quality of water resources in North Carolina
<b>Project Number:</b>	2011NC159B
<b>Start Date:</b>	3/1/2011
<b>End Date:</b>	2/29/2012
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	NC004
<b>Research Category:</b>	Water Quality
<b>Focus Category:</b>	Water Quality, Hydrogeochemistry, Toxic Substances
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	Avner Vengosh, Heileen Hsu-Kim

### Publications

There are no publications.

# **The impact of Coal Combustion Products on the quality of water resources in North Carolina**

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## **WRRI project 2011-1481-01 Progress Report**

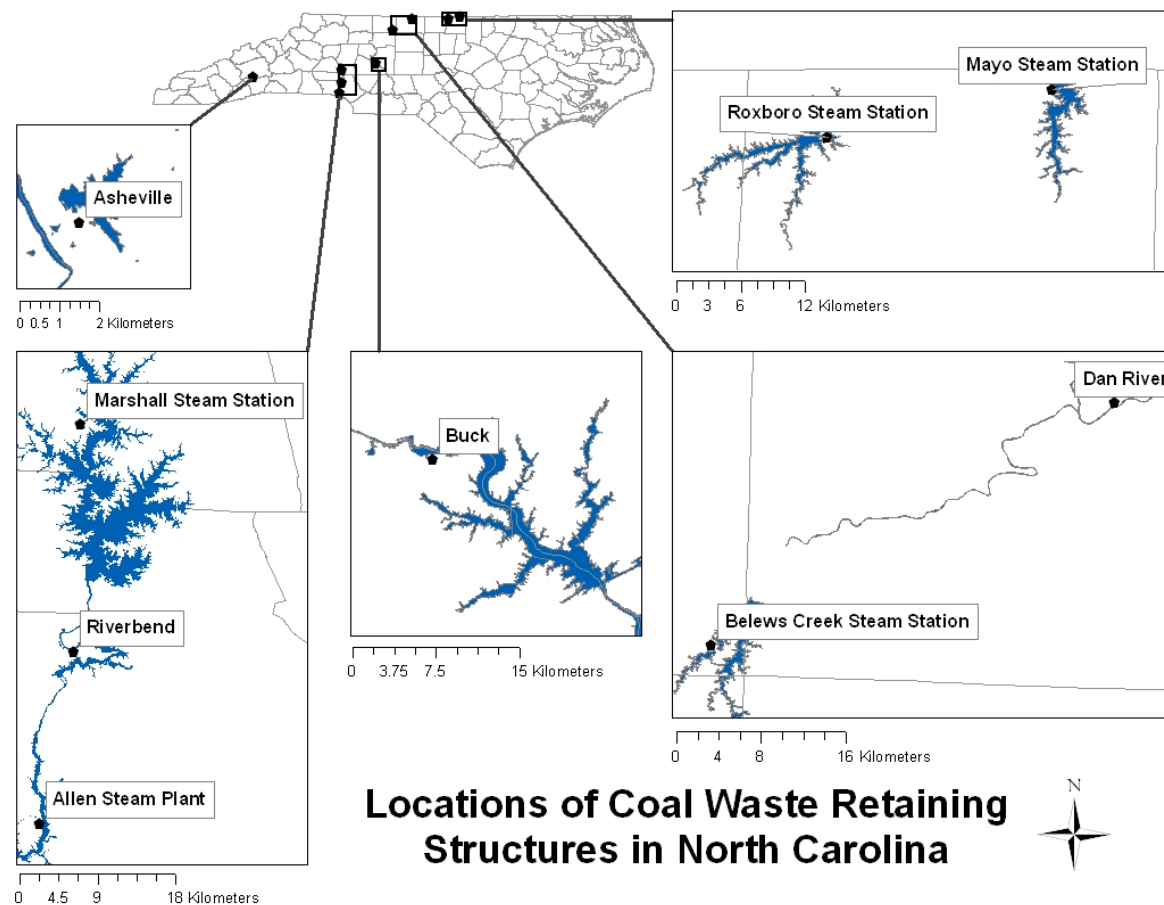
*Duke University*

**September, 2011**

## 1. Introduction and objectives

Coal combustion residues (CCRs) represent one of the largest industrial waste streams in the U.S. Because they are not classified as hazardous waste, disposal, storage ponds, and landfills are generally unlined and, in many instances, are not adequately monitored with respect to their possible effects to nearby water sources. Coal ash storage ponds are precarious because of the potential for continuous leaching of contaminants and their transport to the hydrological system. The long-term impacts of CCRs are largely unknown because monitoring results from discharges of holding ponds and landfills are limited in scope. In a recent nationwide survey of 431 holding ponds, 49 have been assigned a “high hazard potential” rating by the EPA and approximately one-quarter of these are located in North Carolina (Figure 1; Table 1). This fact has been the motivation for initiating this research and collaboration with the NC Department of Environment and Natural Resources (NC DENR) Division of Water Quality.

Nine coal fired plants in North Carolina discharge a total of 554.1 million gallon per day (MGD) of effluents from ash holding ponds and 4315.4 MGD of cooling water (see distribution in Table 1). This massive discharge has a significant impact on the hydrological balance of the water resources associated with these outflow sites and, moreover, on their water quality. The objective of this project is to provide systematic water quality data for each of the CCPs storage sites in NC (Figure 1) and to evaluate their impacts on the water quality of associated water resources.



*Figure 1. Sampling locations of nine surface waters in North Carolina that receive direct runoff or effluent from CCP storage ponds from coal power plants (Map made by R.B. Merola).*

ASH POND DISCHARGE FLOW DATA	AVERAGE FLOW (MGD)	OWNER	TOWN LOCATION	WATER BODY	BASIN	SIZE in Megawatts
Roxboro Steam Station	502.0	Progress Energy	Semora	Hyco Lake	Roanoke	2558 MW
Mayo Steam Station	7.3	Progress Energy	Roxboro	Mayo Reservoir	Roanoke	745 MW
Allen Steam Station	15.3	Duke	Belmont	Catawba River/Lake Wylie	Catawba	1140 MW
Marshall Steam Station	8.4	Duke	Terrell	Catawba River/Lake Norman	Catawba	2090 MW
Belews Creek Steam Station	8.6	Duke	Walnut Cove	Dan River	Roanoke	2240 MW
Asheville Steam Station	3.3	Progress Energy	Arden	French Broad River	French Broad	376 MW
Riverbend Steam Station	4.4	Duke	Mount Holly	Catawba River/Mt Island Lake	Catawba	454 MW
Buck Steam Station	4.2	Duke	Salisbury	High Rock Lake	Yadkin- PeeDee	369 MW
Dan River Steam Station	0.6	Duke	Eden	Dan River	Roanoke	276 MW

*Table 1: NC Lakes with coal fired power plants in the proposed study. Roxboro and Mayo were sampled monthly, while the remaining plants were sampled during summer 2011.*

## 2. Research Activities and field work

Fieldwork for the 2011 WRRI project has taken place throughout the year (Aug 2010-Aug 2011). Field trips to Hyco and Mayo Lakes were made monthly, with the exception of Dec 2010 and July 2011 with only partial sampling events due to extreme weather. During each field trip, the same locations were sampled to ensure regularity and consistency in measurements. A water profile was collected with field parameters, such as dissolved oxygen, conductivity, pH, temperature, and salinity. Water samples were collected at mid lake depth (or in the case of stratification, the two distinct water layers) with a Niskin sampler, and processed for cations, anions, trace metals, alkalinity, Hg, and isotopes. Sediment samples from the lake floor were collected with a Wildco box core; porewater samples were extracted from these sediments samples at the site.

In addition to systematic sampling of Hyco and Mayo lakes, other lakes in North Carolina (*Figure 1*) were sampled the Summer of 2011 and included Lake Norman (5/16/11), High Rock Lake (5/17/11 and 6/13/11), French Broad River (6/15/11), Lake Julian (6/16/11), Belews Lake (7/18/11), Dan River (7/19/11), Lake Wylie (7/25/11), Mt. Island Lake (7/26/11), and Jordan Lake (8/16/11). Jordan Lake was not part of the original plan for the WRRI project, but was added as a piedmont “background” lake (i.e., a lake without an associated power plant).

In each of these lakes the water profile (e.g., temperature, DO) was determined and water samples were collected along the water column, in addition to sampling river/lake bottom sediments and pore water in a similar manner to Hyco and Mayo Lakes. All of the lakes that were sampled in summer 2011 were listed in the original sampling plan in an attempt to establish a “snapshot” observation of NC lake water quality and possible CCRs impact.

**Overall, we have collected thus far about 200 water samples for this WRRI project, which are currently analyzed for major elements, trace elements including As, Se, and Hg, arsenic speciation, and boron and strontium isotopes.**

### 3. Preliminary findings

#### *3.1. Hyco and Mayo Lakes: A twelve-month investigation into the mobilization of toxic elements from CCR storage ponds*

As part of this WRRI project we have systematically investigated Hyco and Mayo Lakes (Figure 1) that directly receive discharge from CCR holding ponds from Roxboro and Mayo steam stations, respectively. Hyco and Mayo Lakes are reservoirs that were built to accept large quantities of effluent from CCR holding ponds at coal power Roxboro and Mayo plants (Figure 1, Table 1). Hyco Lake is surrounded by residential communities and **both lakes** are popular for recreational purposes (e.g., boating, fishing). Preliminary surveys of Hyco and Mayo Lakes by N.C. Department of Environment and Natural Resources (DENR) found that CCR contaminants levels at the outfall of the Roxboro Steam Station (Hyco) and Mayo Steam Station are below EPA maximum contaminant level (MCL) in the downstream surface water. Yet our preliminary observations found high levels that exceed the water standards in pore water, sometimes by a factor of 10 or more (Figure 2). These results could explain why fish tissues from these lakes were observed to exceed EPA wildlife criteria for As and Se. Our data from sampling from Aug 2010 until present have demonstrated that leachable coal ash contaminants in Hyco and Mayo Lakes can be divided into two groups based on their geochemical variations: (1) elements that behave conservatively in the lake water (Ca, Mg, B, Li, Sr) such that their concentrations are dependent on the mass balance between the coal ash effluents and pristine water (Figures 3 and 4); and (2) elements that are associated with the redox state of the water (As, Ba, Mn) and show relatively high concentrations in anoxic deep water during thermal stratification of the lake (Figure 5). These results are consistent with similar trends our group found in river sediments impacted by the TVA coal ash spill in Tennessee. These results indicate that enrichment and bioaccumulation of many contaminants may occur in reduced zones in affected lakes (bottom water, pore water) due to the control of redox conditions and the contaminants’ speciation.

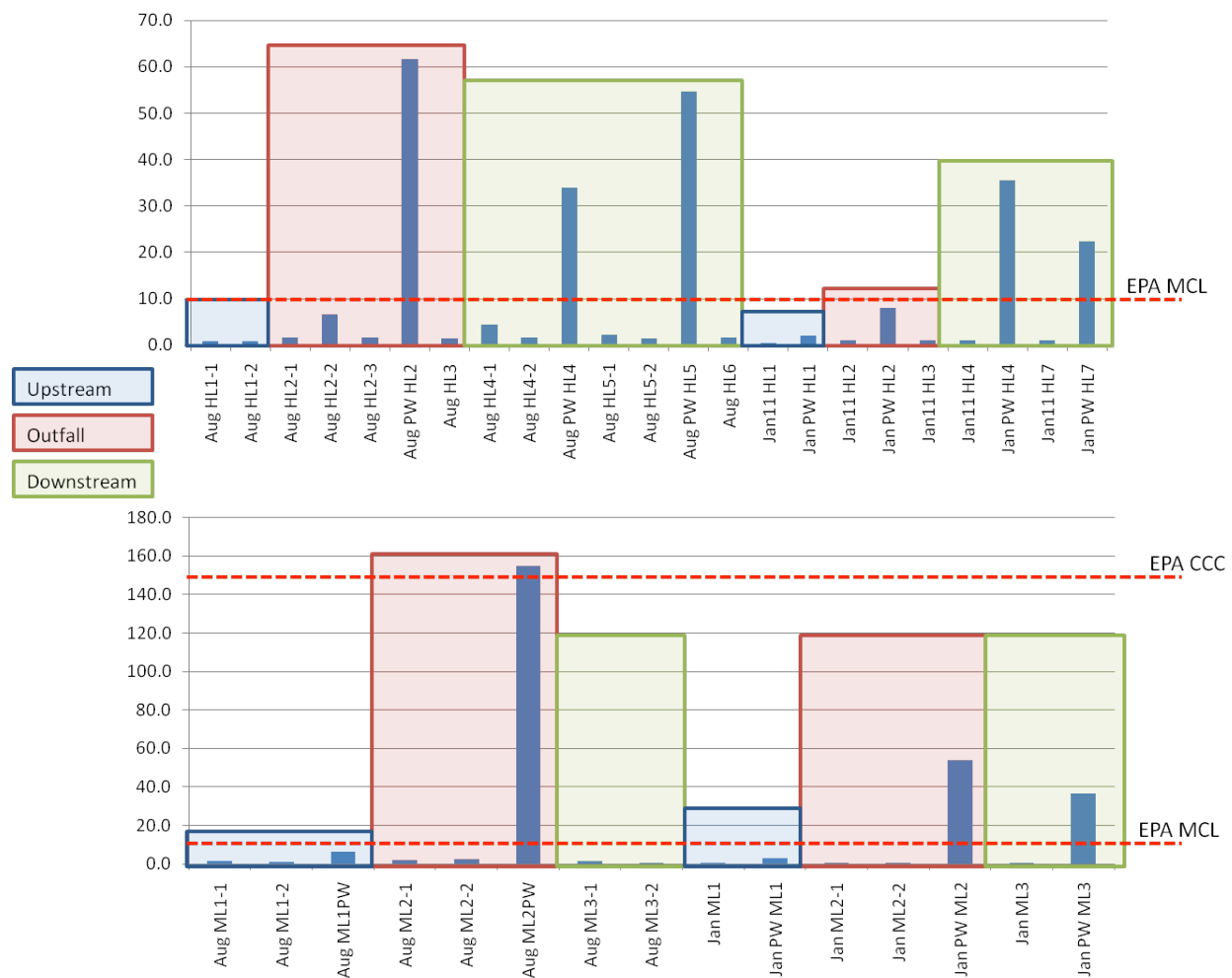
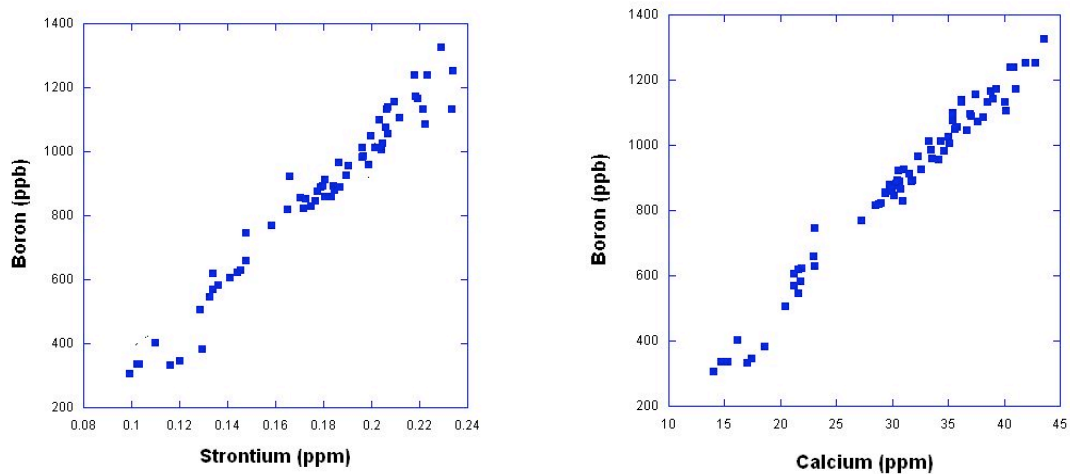


Figure 2. Variations of As concentration (ppb) in surface water and pore water (PW) in Hyco (top) and Mayo (bottom) lakes during August 2010 and January 2011 sampling campaigns. All of the surface water values fall below the EPA MCL, but the contaminants contents in pore water from both near the outfall and downstream exceeded this threshold.



Figures 3 and 4: Concentration of B vs Sr and B vs Ca in Hyco Lake: These overall trends reveal that the concentration of these elements is function of mixing of the effluent and the pristine lake water.

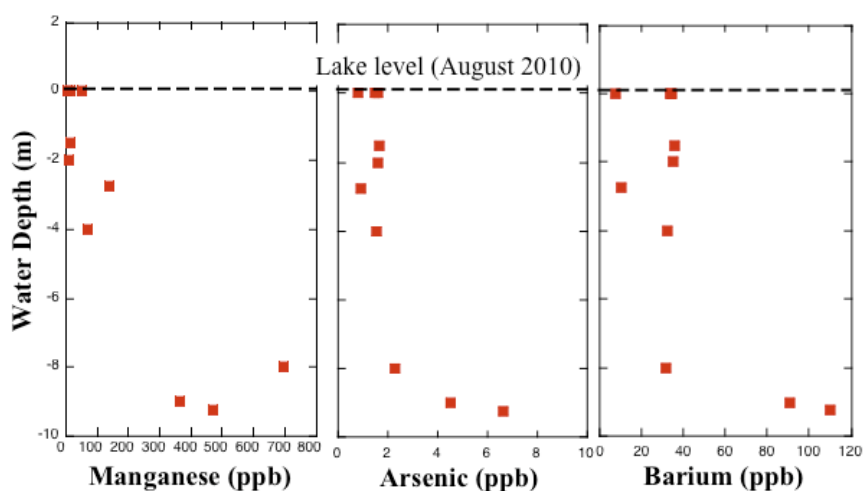


Figure 5. Variations of dissolved Mn, As, and Ba concentrations with water depth at Hyco Lake during August 2010. The relative enrichment of these elements with depth is associated with reducing conditions and thermohaline stratification of the lake water, which suggests that reductive dissolution of Mn-oxides and release of As to the lake water.

The emerging data that was generated so far show that the concentrations of several contaminants (As, B, Se, Sr) were highest at the outfall sampling locations (well above the “background” sites) and remain enriched downstream (in the surface and porewater samples) (Figure 2). For example, boron concentrations varied from 383 to 1,326 ppb (Hyco) and 716 to 3,444 ppb (Mayo) at the outfall, while lake concentrations ranged from 306 to 1,326 ppb in Hyco and 310 to 3,444 ppb at Mayo. The B concentrations are much greater than typical streams and rivers in NC (<50 ppb). The high boron concentrations did not coincide with seasonal low lake levels in Hyco Lake (Figure 6), but instead could be affected by the retention time of the reservoir. An initial run of the boron isotope composition of Hyco and Mayo Lakes provided a negative  $\delta^{11}\text{B}$  value ( $\delta^{11}\text{B} = -2.4\text{‰}$  and  $-5.1\text{‰}$ , respectively), which is consistent with our leaching experiments and the signature of coal ash leachate.

While the levels of contaminants such as arsenic in Hyco Lake demonstrated a clear origin to the lake (i.e. Roxboro plant outfall), mercury in the water did not show the same spatial trend even though Hg concentrations were relatively high during specific sampling events (Figure 7). From August 2010 to February 2011, total mercury concentrations in surface water (170 – 1500 ng/L) were greater than the EPA threshold guideline (12 ng/L) at most sampling locations in Hyco Lake. After this period, Hg concentrations in the lake dropped to below the EPA threshold guideline and were close to field blanks consisting of deionized water that were processed in the same manner as the lake samples. The elevated Hg concentrations were distributed throughout the lake and did not appear to correspond to the plant outfall (site HL-2) as the main source. Furthermore, this period of elevated Hg concentrations corresponded to a period of low water level in the lake (Figure 6), suggesting that the elevated Hg concentrations were caused by retention of Hg-contaminated water from another water source to the lake. The next steps in this work are to assess the spatial and temporal variability of Hg, methylmercury, and other elements (especially selenium) in lake sediments. The potential hazard of elevated methylmercury, which is expected in lake sediments, may be mitigated by selenium, which is known to hinder bioaccumulation of mercury in aquatic organisms.



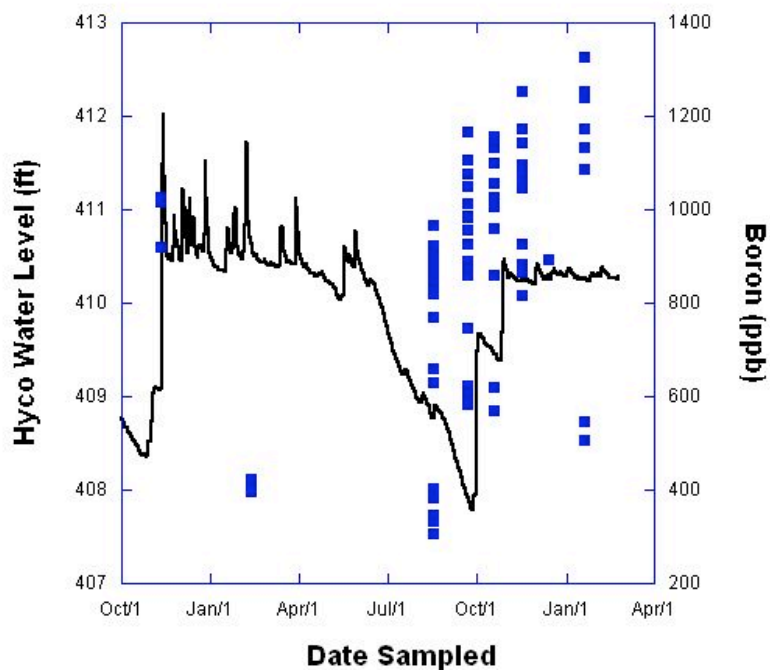


Figure 6: Water level at Hyco Lake and boron concentration in the water column. Normal lake level is at 410.5 feet, at which point the excess water overflows through a spillway.

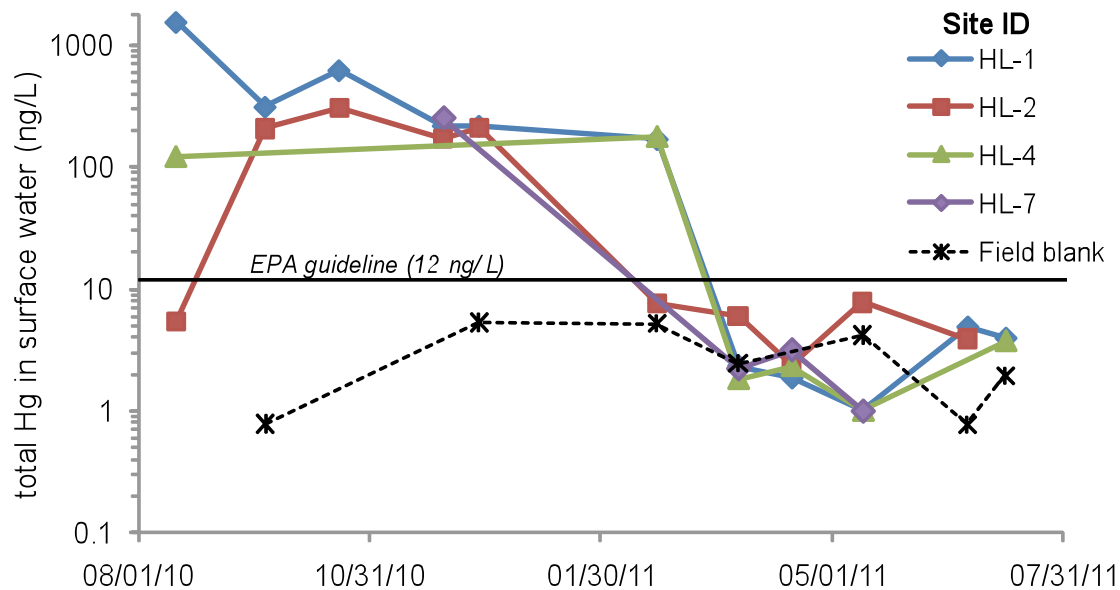


Figure 7: Total mercury (Hg) concentration in the surface water of Hyco Lake. In samples collected from August 2010 to February 2011, Hg concentrations in the water were at least 10 times above the EPA guideline for surface water (12 ng/L). Since March 2011, mercury

*concentrations in the lake were below this threshold and close to Hg measurements in field blanks.*

#### **4. Student Involvement**

Several students have participated in this research project. A PhD student (Laura Ruhl- Division of Earth and Ocean Sciences at the Nicholas School of Environment) has coordinated sampling and analysis of the samples collected, and this project will be a large portion of her dissertation work. Another PhD student (Grace Schwartz- Department of Civil & Environmental Engineering, Pratt School of Engineering) has worked on mercury data collected in this study, which will also be part of her dissertation. Undergraduate student (Katie Barzee - Division of Earth and Ocean Sciences at the Nicholas School of Environment) worked on the porewater chemistry as part of her undergraduate honor thesis. In addition, several other undergraduates and master students participated in the sampling campaigns and worked in the lab

oulants and optimum cleaning strategies for nanofiltration and reverse osmosis membranes treating groundwaters from the

# Identification of membrane foulants and optimum cleaning strategies for nanofiltration and reverse osmosis membranes treating groundwaters from the Castle Hayne and Peedee aquifers

## Basic Information

<b>Title:</b>	Identification of membrane foulants and optimum cleaning strategies for nanofiltration and reverse osmosis membranes treating groundwaters from the Castle Hayne and Peedee aquifers
<b>Project Number:</b>	2011NC160B
<b>Start Date:</b>	6/15/2011
<b>End Date:</b>	6/14/2012
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	NC004
<b>Research Category:</b>	Engineering
<b>Focus Category:</b>	Treatment, Groundwater, Water Supply
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	Orlando Coronell

## Publications

There are no publications.

**Identification of membrane foulants and optimum cleaning strategies for nanofiltration and reverse osmosis membranes treating groundwaters from the Castle Hayne and Pee Dee aquifers: Progress Report 1**

(WRI project#11-03-W, Sub-award agreement#2011-1481-02)

**Prepared by:**

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**Submitted to:**

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## 1. Objective

The objective of this progress report is to present: (i) results on the analysis of water quality of raw and filtered waters from the Peedee and Castle Hayne aquifers; (ii) a description of the bench-scale membrane system built for this project; and (iii) modifications to the original project plans.

## 2. Progress Overview

Water quality analyses have been concluded as proposed in the original research proposal with the exception of particle size distribution. High silt density index in Castle Hayne water after 5  $\mu\text{m}$  filters could be a potential foulant. Ultrafiltration pretreatment would be needed to achieve measurable reductions in dissolved organic carbon (DOC) as filtration through microfiltration membranes, which remove sand and other suspended particles, had negligible effect on DOC content. Fluorescence analysis of effluent waters from filtration tests with 5- $\mu\text{m}$ , 1.2- $\mu\text{m}$ , 0.1- $\mu\text{m}$  and 100-kDa filters suggest that different types of organic carbon (i.e., terrestrial, bio-available and microbial) are removed non-selectively by the filters. Ion concentrations indicate that precipitates are unlikely to form in bulk water, but concentration polarization effects in the vicinity of the membrane interface may result in precipitation of inorganic scale on the membrane surface; calculations relevant to concentration polarization effects will be part of the final report.

The DOC concentration in the Castle Hayne aquifer was more than twice that in the Peedee aquifer, indicating greater potential for organic fouling. Slope ratio ( $S_r$ ) calculations based on fluorescence analyses suggest that organics in the Peedee water have lower molecular weight relative to Castle Hayne water; however, the iron present in the aquifer waters, especially in Castle Hayne water, may have affected  $S_r$  calculations. The effect of iron on  $S_r$  values for Peedee and Castle Hayne waters will be further evaluated in the final report.

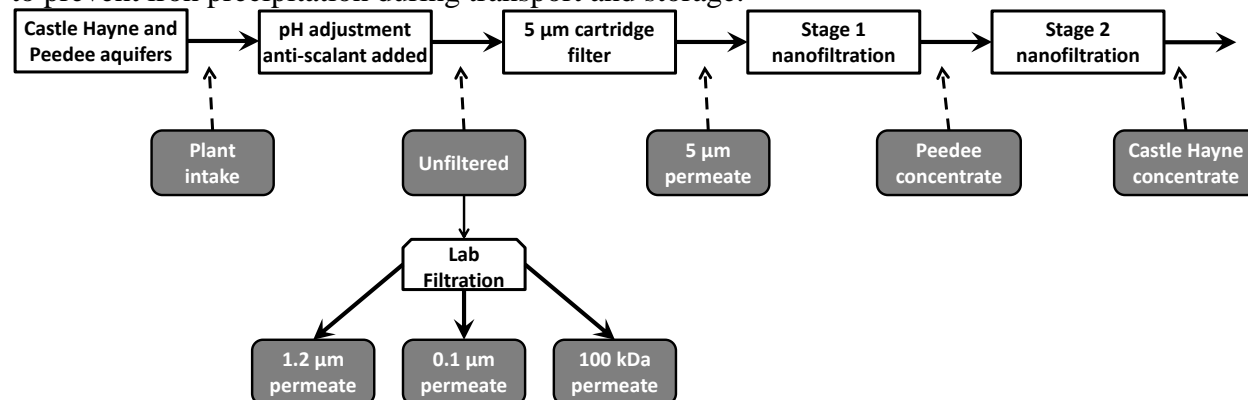
The bench-scale, flat-sheet, cross-flow, high-pressure membrane system that will be used for fouling and cleaning tests has been completed and tests will begin upon receipt of the membranes from the manufacturer. Changes to the original project plans and the reasons motivating such changes are described in Section 7.

The graduate research assistant working on the project (Alex Gorzalski, student of Master of Science in Environmental Engineering) has been trained in the procedures to measure and analyze an array of water quality parameters, both inorganic and organic. Mr. Gorzalski obtained all data and performed all analyses that make up the bulk of this report (Section 4). Mr. Gorzalski has also set up a bench-scale, cross flow, high-pressure membrane system upon training by the PI. The first draft of this report was also written by Mr. Gorzalski. All activities have been performed under supervision of the principal investigator. The next phase of the project will also have involvement of an undergraduate student.

### 3. Materials and Methods

A process flow diagram of the treatment plant and sample collection locations are shown in Figure 1. Water pumped directly from the aquifer before any treatment will be referred to as ‘plant intake’. Water collected after the water conditioning step at the treatment plant (i.e., pH adjustment and anti-scalant addition) will be referred to as ‘unfiltered’ water. The ‘5  $\mu$ m permeate’, ‘Peedee concentrate’ and ‘Castle Hayne concentrate’ labels describe the location where the water samples were collected at the plant. Peedeeconcentrate and Castle Hayne concentrate were sampled from the first stage and second stage, respectively, of nanofiltration membranes. Unfiltered water samples were also further filtered in the laboratory through 1.2  $\mu$ m, 0.1  $\mu$ m, or 100 kDa filters, and corresponding permeate samples were labeled accordingly (see Figure 1). The filter ratings used represent conventional sand filtration (1.2  $\mu$ m), microfiltration (0.1  $\mu$ m), and ultrafiltration (100 kDa) pretreatment steps(Kumar, 2006).

Water samples were collected on August 18 and September 21 of 2011. Nanofiltration concentrate samples were collected only in September. The results shown for all samples other than concentrate samples are waters collected in August unless otherwise specified. Samples were collected in 5-gallon polyethylene containers for transport from the treatment plant to the University of North Carolina at Chapel Hill. At the university, samples were stored at 4°C until analysis. Collapsible containers were used to minimize head space in the container in an attempt to prevent iron precipitation during transport and storage.



**Figure 1. Diagram of treatment process at the Cape Fear Public Utility Authority (CFPUA) Groundwater Nanofiltration Treatment Plant (Wilmington, NC) and water sample collection locations. White boxes depict treatment processes at the plant. Dark boxes depict sampling locations. Unfiltered samples collected after water conditioning were further filtered at the laboratory using membranes with nominal pore sizes of 1.2  $\mu$ m, 0.1  $\mu$ m, or 100 kDa. The Peedee water treatment train uses TFC–S membranes (Koch Membranes, Wilmington, MA) in both nanofiltration stages. The Castle Hayne water treatment train uses TFC–ULP (Koch Membranes) and TFC–S membranes in the first stage and second stage, respectively, of nanofiltration.**

Water quality analyses were divided into three groups: (1) commonly used water quality indicators, (2) inorganic parameters, and (3) organic parameters. Each group of parameters is thoroughly described in Section 4. Materials and methods for each parameter are summarized in Table 1. Membranes filters for laboratory use were selected to minimize protein binding that would bias the measurement of Group 3 parameters. All Group 1 parameters were measured by standard methods (American Society for Testing and Materials–ASTM or American Water

Works Association–AWWA) except for turbidity, for which a Hach 2100P portable turbidimeter (Loveland, CO) was used. Group 2 and 3 parameters were measured as described in Table 1.

**Table 1. Materials and methods for measuring water quality parameters.**

<b>Water Quality Parameter</b>	<b>Instrument/Method</b>
<b>Group 1 Parameters</b>	
Turbidity	Portable turbidimeter - Hach 2100P (Loveland, CO)
Silt density index (SDI)	Standard methods (ASTM, 2002)
Total suspended solids (TSS)	Standard methods (AWWA, 2006)
Particle size distribution	Not performed yet-Dynamic light scattering and/or particle count
<b>Group 2 Parameters</b>	
Hardness	Total hardness test kit - Hach (Loveland, CO)
Alkalinity	Standard methods (AWWA, 2006)
Conductivity	Benchtop conductivity meter - Mettler Toledo (Columbus, OH)
Disolved ions	Al, Fe, Mn, Mg, Si, Na: ICP-MS - Agilent Technologies (Santa Clara, CA) Cl: Ion selective electrode - Accumet/Fisher (Pittsburgh, PA)
<b>Group 3 Parameters</b>	
Dissolved organic carbon (DOC)	Total organic carbon analyzer - Shimadzu TOC-V SPH (Columbia, MD)
Ultraviolet absorbance (UVA)	Diode array spectrophotometer - Hewlett Packard (Palo Alto, CA)
Excitation-emission matrices (EEMs)	Fluorog-321 spectrofluorometer with xenon arc lamp, synapse CCD detector - HORIBA Jobin Yvon (Edison, NJ)
<b>Laboratory Pretreatment</b>	
Conventional sand filtration	1.2 $\mu\text{m}$ cellulose acetate filter - General Electric (Tervose, PA)
Microfiltration	0.1 $\mu\text{m}$ polyvinylidene fluoride (PVDF) filter - Millipore (Billerica, MA)
Ultrafiltration	100 kDa regenerated cellulose filter - Millipore (Billerica, MA)

## 4. Water Quality Analysis Results

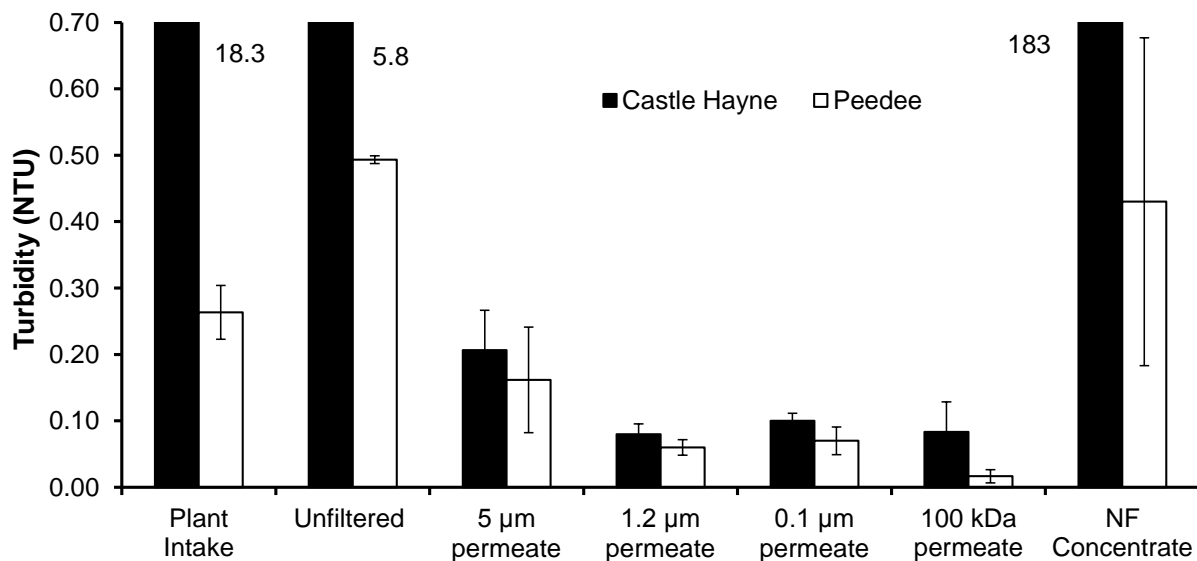
Numerous water quality parameters, divided into three groups, were evaluated to identify potential membrane foulants. Group 1 parameters include turbidity, silt density index (SDI), total suspended solids (TSS), and particle size distribution/counts. Group 1 parameters correspond to parameters for which there are “rule-of-thumb” maximum values or ranges that are commonly recommended for waters feeding nanofiltration membrane systems. Group 2 parameters consisted of common inorganic contaminant concentrations and inorganicfoulant indicators including hardness, alkalinity, conductivity, and numerous dissolved ion species. Group 3 parameters parallel those of Group 2 but for organic species. Group 3 indicators include total organic carbon (TOC), UV absorbance at 254 nm (UVA), specific UV absorbance (SUVA=UVA/DOC), excitation-emission matrices (EEMs), fluorescence index (FI), slope ratio (Sr), and fluorescence ratios of peaks of particular interest in EEMs.

All water quality analyses have been completed with the exception of particle size distribution. Parallel factor (PARAFAC) analysis of EEMs will be performed once a greater number of sampleshas been analyzed.



#### 4.1. Group 1 Parameters: “Rule-of-Thumb” Parameters

Recommendations by the membrane manufacturer Koch Membrane Systems (Wilmington, MA) state that turbidity of feed water should not exceed 1 NTU (Koch, 2010). Turbidity in the Castle Hayne aquifer was 18.3 NTU, but decreased to approximately 0.2 NTU after the 5  $\mu\text{m}$  cartridge filters as shown in Figure 2. Water from the Peedee aquifer did not exceed the 1 NTU turbidity limit either in the source or in the concentrate. Turbidity in membrane concentrate from the Castle Hayne was particularly high, over 180 NTU. This result could indicate high fouling potential in the second stage of filtration. However, pH was not adjusted during sampling and thus iron precipitation between sample collection and turbidity measurement may have biased the result. Turbidity will be measured at the time of collection in the future to ensure that precipitation will not bias the results.

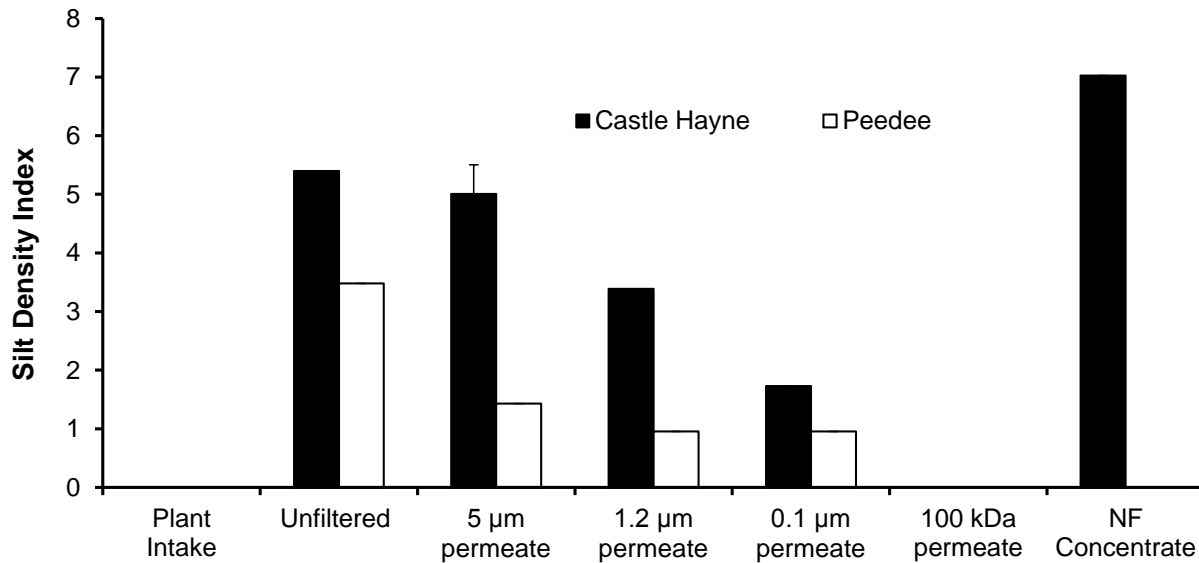


**Figure 2. Turbidity results for Castle Hayne and Peedee waters. Values for plant intake, unfiltered, and nanofiltration concentrate from the Castle Hayne exceeded the limits of the y-axis but were 18.3 NTU, 5.8 NTU, and 183 NTU, respectively.**

Silt density index (SDI) should be less than or equal to 5 according to the membrane manufacturer (Koch, 2010). SDI was measured for water samples from both aquifers as shown in Figure 3. All Peedee water after the 5  $\mu\text{m}$  filtration step had an SDI lower than two, indicating relatively low fouling potential. The Castle Hayne 5- $\mu\text{m}$  filtered sample had an SDI of approximately 5, the upper limit of SDI.

To perform SDI tests with Castle Hayne water, the collected samples from the second-stage concentrate was diluted 2.5 times with lab grade water to a concentration representative of first stage concentrate (i.e., the concentration factor in stage 2 is 2.5). Despite sample dilution, Castle Hayne concentrate still exceeded the recommended SDI limit of 5, indicating the potential for colloidal and particulate fouling. Due to limited sample volume, SDI from the plant intake, 100 kDa filtered samples, and Peedee concentrate was not tested. SDI will be measured for plant intake and Peedee concentrate prior to the final report. It is not necessary to measure the SDI for the samples filtered through 100-kDa membranes since the SDI values for the samples from both

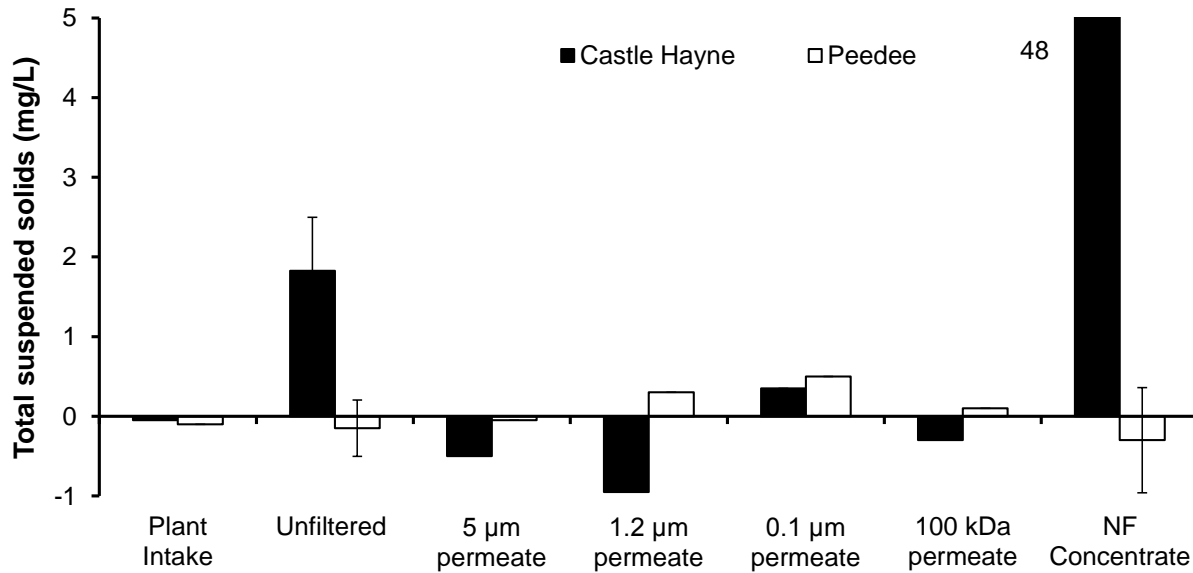
aquifers filtered through the 0.1- $\mu$ m membranes show already SDI values lower than 2 which is only 40% of the maximum recommended value of 5.



**Figure 3. Silt density index (SDI) results for Castle Hayne and Peedee waters. Due to limited sample volume, SDI was not measured for plant intake, 100-kDa filtered, or Peedee concentrate samples. Castle Hayne concentrate was diluted 2.5 times to achieve a water quality representative of the concentrate stream of the first nanofiltration stage at the CFPWA groundwater nanofiltration treatment plant.**

Results for total suspended solids (TSS) are shown in Figure 4. Although no recommendation is given by the manufacturer for TSS in feed waters, higher TSS corresponds to higher fouling potential. In most samples, TSS was not significantly different from zero. Only unfiltered and concentrate waters from the Castle Hayne aquifer had significant TSS. Given that TSS is negligible in samples collected after the cartridge filters, the influent TSS to the first stage membrane filtration is not likely a significant foulant in water of either aquifer.

The TSS in the concentrate of the first stage of the Peedee train is also negligible, which indicates that suspended solids are not likely to cause significant fouling in the second stage membrane filtration in the Peedee treatment train. The TSS in the concentrate of the second stage membrane filtration of the Castle Hayne treatment train, however, was measured to be 48 mg/L. Given that the nanofiltration treatment at the plant operates at 80 percent recovery (i.e., solids concentration factor of 5-fold assuming 100% solids rejection), concentration of solids in the membrane feed water (i.e., 5 $\mu$ m permeate) does not account for the increase in TSS. Given that Castle Hayne waters have a high concentration of dissolved solids including iron, one possible origin of the relatively high TSS in the membrane concentrate may be precipitates. The TSS in Castle Hayne nanofiltration concentrate waters will be measured again with samples whose pH will have been dropped to prevent iron precipitation. Additionally, solubility products are analyzed in following section together with as well as Group 2 parameters.



**Figure 4. Total suspended solids (TSS) in Castle Hayne and Peedee waters. Negative values indicate negligible TSS. For samples tested multiple times, zero was contained within the 95 percent confidence interval, and therefore corresponding results are not statistically distinguishable from zero.**

## 4.2.Group 2 Parameters: Inorganic Parameters

Detailed results for alkalinity, hardness, conductivity, and pH for each of the waters at each of the treatment stages can be found in Appendix 3. In general, each treatment step in the treatment plant or laboratory filtration had the expected effect on each of the parameters measured.

Alkalinity and pH were affected significantly only by the pH adjustment and nanofiltration steps at the plant. Although the alkalinity in the two aquifers is comparable, the pH of Castle Hayne water is adjusted to 6 at the plant by adding sulfuric acid, whereas Peedee water is kept at a pH of about 7. The motivation to decrease the pH of the Castle Hayne water is to prevent iron precipitation/oxidation as the content of iron in Castle Hayne water is about 100 times larger than in Peedee water. The higher pH in the Peedee water after the water conditioning step results in significantly higher alkalinity than in the Castle Hayne water. Lowering the pH with sulfuric acid prior to filtration reduces the propensity to form alkaline scales such as calcium carbonate, but increases calcium sulfate precipitation and adsorbability of natural organic matter to membrane surfaces (Her, 2000). For both the Castle Hayne and Peedee waters, alkalinity decreased when the pH was decreased and increased in the concentrate stream of the nanofiltration step, as expected. The pH in the concentrate stream increased for the Castle Hayne water and decreased for the Peedee water. Increased pH in membrane concentrate could be due to the negative rejection of protons by the membrane (Zhu, 2007).

Hardness and conductivity in the plant intake are relatively the same for both waters at  $\approx 250$  mg/L as  $\text{CaCO}_3$  and  $\approx 550$   $\mu\text{S}/\text{cm}$ , respectively. Only the nanofiltration step in the treatment plant has an effect in hardness and alkalinity. Remembering that all membranes in the treatment plant have  $\approx 98\%$  rejection of hardness and that the Castle Hayne concentrate sample was collected after the second nanofiltration stage, then the hardness in the concentrate sample was expected to

be  $\approx 5$  times higher than in the plant intake, which is consistent with the measured value of 1263 mg/L as  $\text{CaCO}_3$  in the concentrate stream. For Pee Dee water, the measured value of 405 mg/L as  $\text{CaCO}_3$  in the first-stage nanofiltration concentrate sample agreed well with the expected  $\approx 2$ -fold hardness concentration factor. For both waters, the experimental concentration factor of hardness was consistent with that of magnesium as measured by ion coupled plasma mass spectrometry (ICP-MS) (see Table 2). Measured conductivities in nanofiltration concentrate samples were consistent with values expected from the conductivities of feed waters. Given that the TFC-S and TFC-ULP membranes that make up the nanofiltration stages have 85 and 98.5 percent rejection (Koch, 2010) of chloride, respectively, then the theoretical conductivities of Castle Hayne and Pee Dee concentrate samples were calculated as 2,350  $\mu\text{S}/\text{cm}$  and 970  $\mu\text{S}/\text{cm}$ , respectively, which agree well with the corresponding measured values of 2,030  $\mu\text{S}/\text{cm}$  and 780  $\mu\text{S}/\text{cm}$ .

Table 2 contains concentrations of select inorganic ions. Aluminum, iron, magnesium, manganese, silica, and sodium were measured by inductively coupled plasma mass spectroscopy (ICP-MS). Chloride was measured via ion selective electrode and calcium was calculated from the measured concentrations of hardness and concentrations of multivalent cations. Refinement of the ICP-MS method should allow for direct measurement of calcium and sulfide, and will be included in the final report.

**Table 2. Concentrations of select ions in Castle Hayne and Pee Dee waters.**

	<b>Unfiltered (mg/L)</b>	<b>0.1 <math>\mu\text{m}</math> (mg/L)</b>	<b>100 kDa (mg/L)</b>	<b>Concentrate (mg/L)</b>
<b>Castle Hayne</b>				
Aluminum	0.007	0.007	0.004	0.005
Chloride	29.9	29.9	29.4	98.7
Calcium*	104.6	103.5	100.5	478.3
Iron	6.5	6.3	6.2	14.2
Magnesium	2.2	2.4	2.3	10.8
Manganese	0.09	0.10	0.09	0.35
Silica	14.2	15.4	13.1	62.9
Sodium	8.1	8.8	8.6	29.9
<b>Pee Dee</b>				
Aluminum	0.002	0.003	0.013	0.013
Chloride	51.6	51.6	51.6	77.7
Calcium*	92.2	93.0	90.3	143.0
Iron	0.07	0.06	0.06	0.09
Magnesium	7.8	8.1	7.7	11.7
Manganese	0.01	0.01	0.02	0.02
Silica	10.9	10.9	10.0	15.8
Sodium	20.7	21.8	20.4	29.7

\*Calcium calculated as hardness less sum of multivalent cations

\*Calculated as the difference between hardness and the summation of multivalent cations

The Peedee aquifer has a higher concentration of inorganic ions such as calcium and chloride, but the Castle Hayne has more iron and manganese. Dissolved iron precipitates when exposed to oxygen, giving Castle Hayne water a distinct orange color if exposed to air as shown in Figure 5. Prior to air exposure, Castle Hayne water appears clear.



**Figure 5. Visual comparison of the Peedee (left) and Castle Hayne (right) waters when exposed to air. Before exposure to air, Castle Hayne water also looks clear.**

Ion concentrations were used to calculate ion activity products for common precipitates in groundwater systems. Table 3 compares ion activity products to the solubility product,  $K_{so}$ , for hydroxy and carbonate complexes. A species readily precipitates if its ion activity product is greater than the solubility product. Ionic strength and activities were calculated as detailed elsewhere (Benjamin, 2002).

From Table 3 it is apparent that there will not be a significant formation of hydroxy or carbonate complexes in bulk water. In Castle Hayne concentrate, ion activity products for iron hydroxide and calcium carbonate were both within an order of magnitude of their corresponding solubility products. During membrane filtration, ion concentrations are higher at the membrane interface due to concentration polarization (Schafer, 2006), and therefore scale formation may occur at the membrane surface even when bulk water concentrations are too low to form precipitates. An analysis of possible concentration polarization effects will therefore be part of the final report. The treatment plant personnel have also described cleaning solutions as white and cloudy upon leaving the membrane. This might indicate the presence of iron hydroxide and calcium carbonate, both of which are white in color (Shipko, 1956).

Peedee nanofiltration concentrate samples were obtained after the first stage of membrane filtration. As a result, the ion concentrations in the second stage concentrate would be greater.

Assuming all ions were further concentrated 2.5 times in the second stage, the ion activity products would still be significantly lower than the solubility products in Table 3. The ion activity product of calcium carbonate would be the closest to its corresponding solubility product (i.e., an order of magnitude lower). As for the Castle Hayne water, an analysis of possible concentration polarization effects for Peedee water will be part of the final report.

**Table 3. Solubility product and ion activity products for hydroxy and carbonate complexes in Castle Hayne and Peedee waters.**

	<b>K<sub>so</sub></b>	<b>Unfiltered (mg/L)</b>	<b>0.1 µm (mg/L)</b>	<b>100 kDa (mg/L)</b>	<b>Concentrate (mg/L)</b>
<b>Castle Hayne</b>					
Ca(OH) <sub>2</sub>	4.7E-06	1.5E-19	3.8E-19	1.1E-18	2.2E-16
Fe(OH) <sub>2</sub>	4.9E-17	6.7E-21	1.7E-20	5.0E-20	4.7E-18
Mg(OH) <sub>2</sub>	5.6E-12	5.2E-21	1.4E-20	4.3E-20	8.2E-18
Mn(OH) <sub>2</sub>	2.1E-13	9.5E-23	2.6E-22	7.1E-22	1.2E-19
CaCO <sub>3</sub>	5.0E-09	1.4E-12	2.2E-12	3.7E-12	2.1E-10
FeCO <sub>3</sub>	2.1E-11	6.2E-14	9.5E-14	1.6E-13	4.4E-12
MgCO <sub>3</sub>	6.8E-06	4.8E-14	8.2E-14	1.4E-13	7.7E-12
MnCO <sub>3</sub>	2.2E-11	8.8E-16	1.5E-15	2.3E-15	1.1E-13
<b>Peedee</b>					
Ca(OH) <sub>2</sub>	4.7E-06	2.6E-18	6.7E-18	1.2E-17	2.4E-18
Fe(OH) <sub>2</sub>	4.9E-17	1.4E-21	3.0E-21	6.1E-21	1.0E-21
Mg(OH) <sub>2</sub>	5.6E-12	3.6E-19	9.7E-19	1.7E-18	3.2E-19
Mn(OH) <sub>2</sub>	2.1E-13	2.2E-22	7.1E-22	1.5E-21	2.3E-22
CaCO <sub>3</sub>	5.0E-09	8.2E-12	1.3E-11	1.8E-11	1.3E-11
FeCO <sub>3</sub>	2.1E-11	4.5E-15	5.9E-15	8.7E-15	5.5E-15
MgCO <sub>3</sub>	6.8E-06	1.1E-12	1.9E-12	2.5E-12	1.7E-12
MnCO <sub>3</sub>	2.2E-11	6.9E-16	1.4E-15	2.2E-15	1.2E-15

### 4.3 Group 3 Parameters: Organic Parameters

Natural organic matter in the tested waters was characterized by measuring dissolved organic carbon (DOC), UV absorbance (UVA) and fluorescence excitation-emission matrices (EEMs), and by calculating the specific UV absorbance (SUVA), slope ratio (Sr), fluorescence index (FI) and fluorescence ratios of peaks of particular interest in EEMs (see below). The EEMs for the samples analyzed are shown in Appendix 4. EEMs can be used to characterize hydrophobic molecules, biopolymers, and humics which are likely to cause membrane fouling (Amy, 2008). Parallel factor analysis (PARAFAC) uses statistics to identify the type of organics (i.e., terrestrial,

bio-available and microbial) present in the water based on EEMs data. PARAFAC requires a large number of samples, and thus will not be performed until the final progress report.

Table 4 shows results for DOC, UVA and SUVA. DOC was measured for unfiltered, 0.1  $\mu\text{m}$  filtered, 100 kDa filtered, and nanofiltration concentrate samples collected in September 2011. The 5  $\mu\text{m}$  and 1.2  $\mu\text{m}$  samples were not run because a 0.45 micron filtration is performed on all samples prior to DOC analysis to protect the instrument. Table 4 shows that DOC in the Castle Hayne source water was approximately twice that observed in the Peedeesource water. While for both waters DOC was greatly reduced after 100 kDa filtration relative to 0.1  $\mu\text{m}$  filtration, there was no significant change in UVA, therefore resulting in increased SUVA values. This suggests that the filterable fraction of natural organic matter is separate from the UV absorbent fraction. The SUVA values obtained were typical of natural water samples, except for the value of the 100 kDa filtered Castle Hayne sample which was higher than typically observed. Values of SUVA are strongly correlated with percent aromaticity (Weishaar, 2003), and thus hydrophobicity, with high SUVA values often indicating a larger hydrophobic fraction of organic matter, and suggesting a greater potential for membrane fouling (USEPA, 2005). Given the concentration factors of 5 for the second stage nanofiltration concentrate of Castle Hayne water and of 2 for the first stage nanofiltration concentrate of Peedee water, it can be demonstrated that the rejection of DOC is 81% for the Castle Hayne treatment train and 85% for the Peedee treatment train.

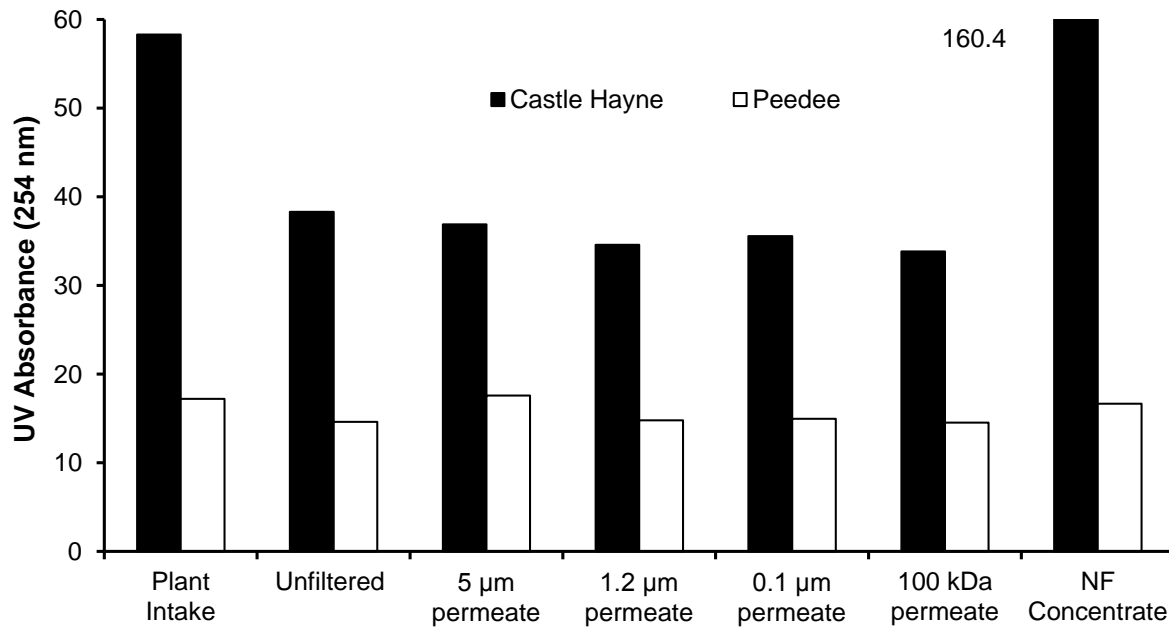
Neglecting the potential adsorption of organics by media filtration and microfiltration pretreatment, Table 4 also demonstrates that these two technologies would remove negligible organics. In contrast, ultrafiltration (i.e., 100 kDa filter) did reduce significantly the concentration of DOC. Also, given that reductions in DOC for 100 kDa filtration occur together with negligible change in UV absorbance, UV absorbance cannot be used as an indicator of DOC.

**Table 4. DOC, UVA, and SUVA measurements in the Castle Hayne and Peedee Aquifers (September 2011).**

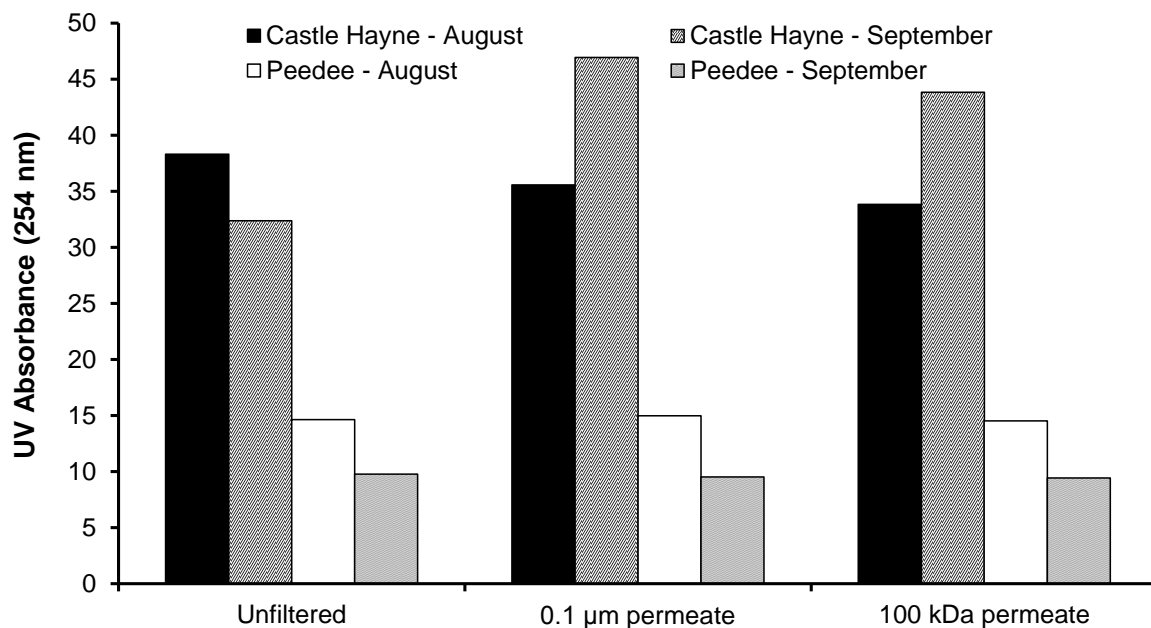
	Castle Hayne			Peedee		
Filtration treatment	DOC (mg/L)	UVA ( $\text{m}^{-1}$ )	SUVA (L/mg-m)	DOC (mg/L)	UVA ( $\text{m}^{-1}$ )	SUVA (L/mg-m)
Unfiltered	8.7	32.4	3.7	3.7	9.8	2.7
0.1 $\mu\text{m}$ permeate	9.2	46.9	5.1	3.8	9.5	2.5
100 kDa permeate	4.4	43.8	10.0	2.7	9.4	3.5
Concentrate	35.3	160.4	4.5	6.2	16.7	2.7

Figure 6 demonstrates that filtration has a negligible effect on UV absorbance, particularly in the Peedee aquifer. Decrease in absorbance between plant intake and unfiltered samples is most likely a function of pH adjustment and anti-scalant addition, as anti-scalants cause shifts in the UV absorption spectrum of iron (Kavitha, 2011). Results for UVA in Figure 6 differ from those in Table 4 because of different sampling dates. The increase in UVA that occurred for the Castle Hayne samples collected in September 2011 after 0.1  $\mu\text{m}$  and 100 kDa filtration as shown in Table 4 did not occur in water from the Peedee aquifer, or in water from the Castle Hayne aquifer collected in August 2011 as shown in Figure 7. No explanation for the increase in UVA

after filtration for the September Castle Hayne water could be found. Additional samples will be collected and the UVA and DOC of unfiltered, 5  $\mu\text{m}$  filtered, and nanofiltration permeate samples will be measured. Published rejection of UVA by TFC-S membranes using surface waters range from approximately 50% to 70% (J. Yoon, 2005).



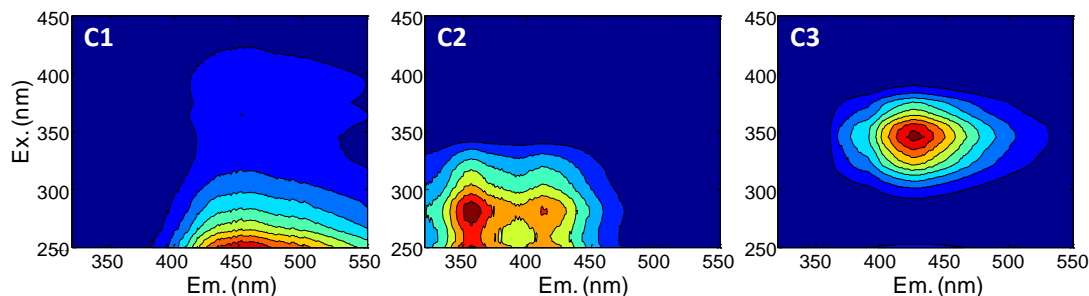
**Figure 6. UV absorbance at 254 nm (UVA) in Castle Hayne and Pee Dee waters at various levels of treatment. All samples were collected in August 2011, except for nanofiltration concentrate samples which were collected in September 2011.**



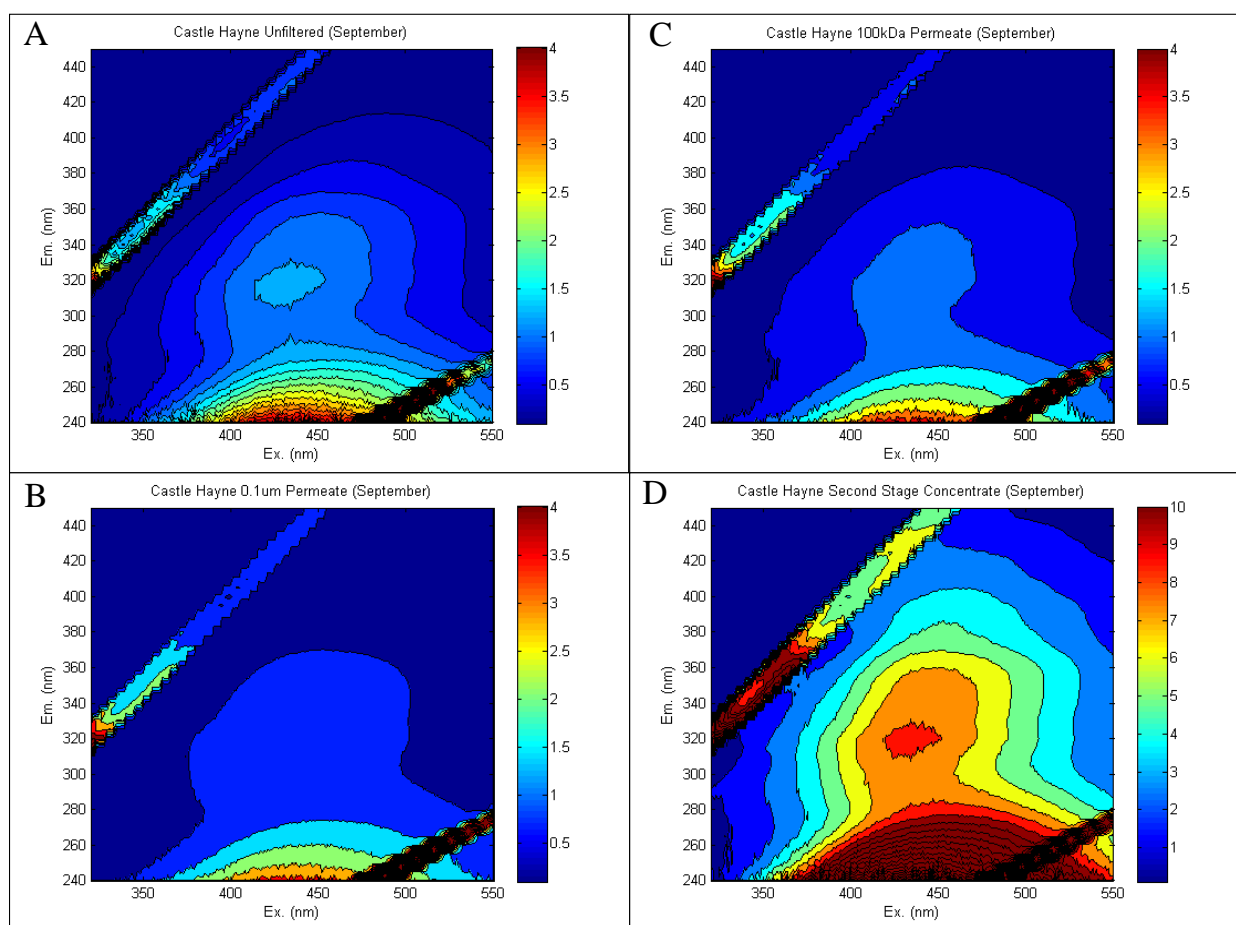
**Figure 7. Comparison between the UV absorbance at 254 nm (UVA) in Castle Hayne and Pee Dee waters collected in August 2011 and in September 2011.**



Parallel factor (PARAFAC) analysis separates the fluorescent signature of aqueous organic matter into a number of components, as shown in Figure 8. Components one, two, and three are associated with organic matter from plants and soil, bio-available and nitrogen-containing organic matter, and microbially-derived materials, respectively. A large number of samples must be analyzed from the same source water in order to perform representative PARAFAC analysis.



**Figure 8. Fluorescence excitation-emission matrices (EEMs) showing the main components in the fluorescent signature of organic matter. Color represents fluorescence intensity in Raman units with blue and red denoting the least and most intense, respectively. Component 1 (C1) is associated with higher plants and soil precursor material, Component 2 (C2) with bio-available organic matter and organic nitrogen, and Component 3 (C3) with microbially-derived material.**



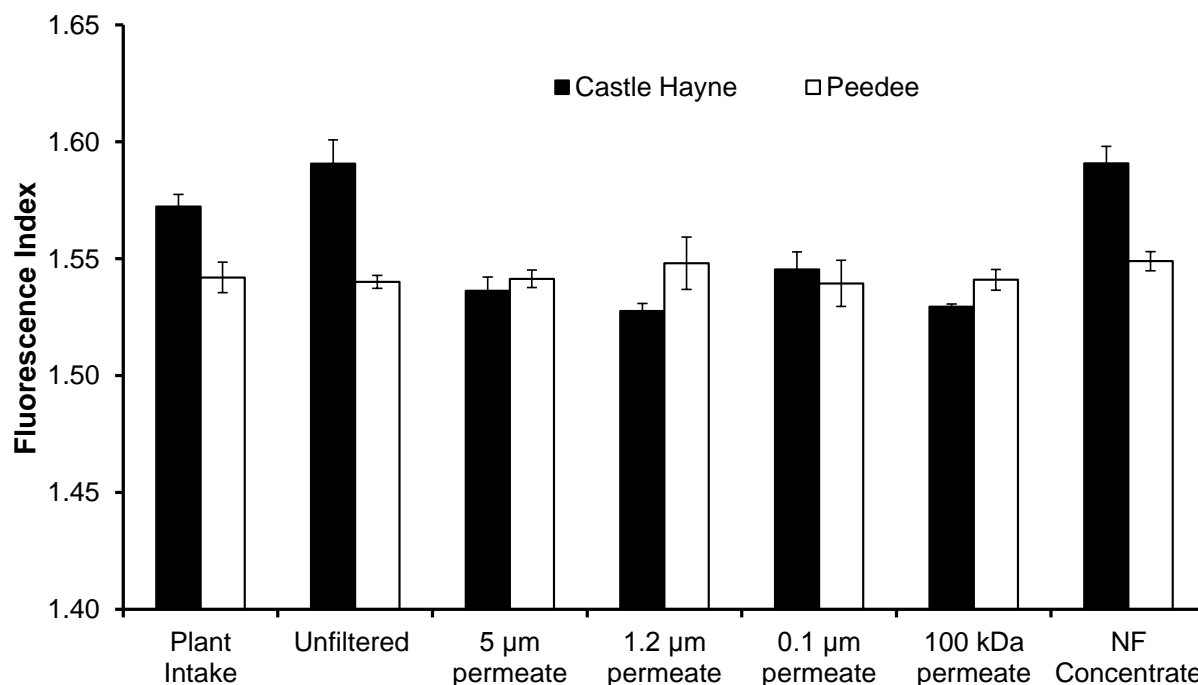
**Figure 9. Excitation-emission matrices (EEMs) for samples collected from the Castle Hayne treatment train in September. Samples include (A) influent after pH adjustment and anti-scalant addition, (B) 0.1um filter effluent, (C) 100kDa filter effluent, and (D) second stage membrane concentrate. Note that panel D has a different scale than A-C.**

With the limited number of samples that have been analyzed thus far, PARAFAC cannot be performed. However, a visual comparison can be made between EEMs generated in the laboratory and those in Figure 8. From visual inspection, samples from both aquifers appear to be rich in plant and soil precursor material (Component 1). Figure 9 includes EEMs from samples collected in September 2011 from the Castle Hayne treatment train. The dark  $\approx 45^\circ$  lines in each plot are an artifact of Rayleigh scattering in the sample rather than organic content. Differences in both the C1 and C3 regions between the unfiltered sample (panel A) and the two filtered samples (panels B and C) indicate the removal of fluorescent organic matter during filtration. As expected, membrane concentrate has concentrated levels of organics, as seen in panel D. The difference in fluorescence between concentrate and unfiltered water is more pronounced than what Figure 9 shows as the scale of intensity has a maximum intensity of 10 raman units in panel D rather than 4 for all other panels.

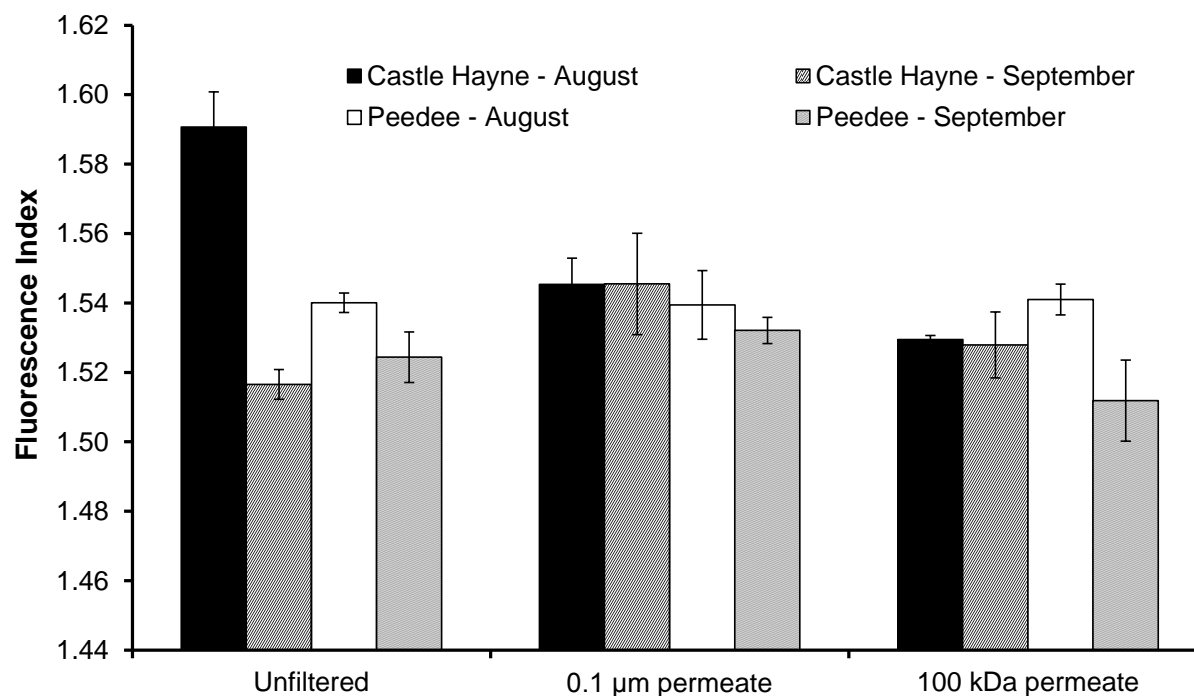
In addition to analyzing the three regions (C1, C2, and C3) from EEM plots, data used to generate EEMs can be used to calculate other parameters, including fluorescence index. Fluorescence index (FI) is a proxy for organic matter source. FI is calculated as the ratio of 470 nm emission intensity over 520 nm emission intensity at an excitation wavelength of 370 nm. An FI greater than 1.45 indicates a significant organic content of microbial origin while an FI lower than 1.40 indicates a lower organic content of microbial origin. An FI between 1.45 and 1.40 constitutes mixed source. Figures 10 and 11 suggest that a significant fraction of the natural organic matter (NOM) in all samples is of microbial origin. The increase in FI from plant intake to the unfiltered sample shown in Figure 10 may be attributable to pH change or addition of anti-scalant. Filtration processes other than nanofiltration appear to decrease the FI with respect to the unfiltered Castle Hayne sample, thus suggesting that organics of microbial origin are preferentially removed, perhaps sorbed, by the filters. For the Pee Dee water, the FI remains unchanged regardless of the type of filtration applied which means that there is no preferential removal of either microbial or terrestrial organic matter.

There was minimal difference in FI between the August and September sampling events, as shown in Figure 11, with the exception of Castle Hayne unfiltered water. The significant change in FI between unfiltered and permeate samples suggests that unfiltered water from August contained organics that were preferentially removed during filtration. However, such organics were not present in the September sampling. FI for unfiltered Castle Hayne water will be measured again to determine if the August sample was an outlier.

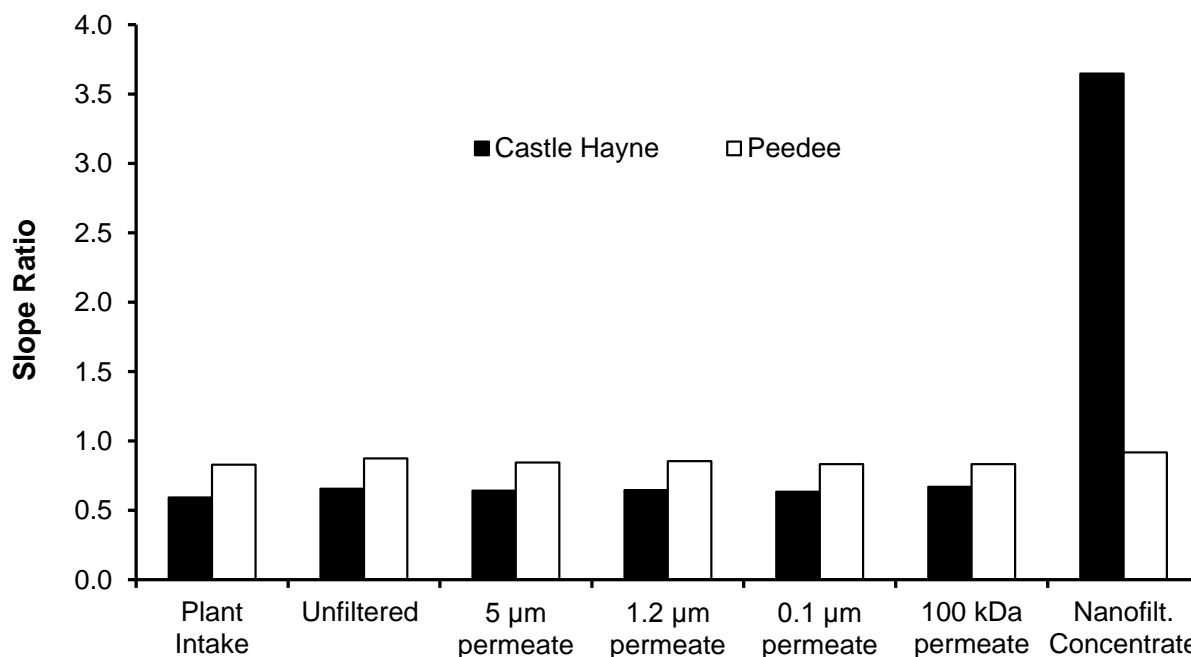
Slope ratio (Sr) is used as an indicator of molecular weight (Helms, 2008), and is calculated by dividing the slope of UV absorbance between 275 and 295 nm wavelengths with the slope between 350 and 400 nm. Samples with a higher content of low-molecular weight organics have a high slope ratio, while low slope ratio indicates high molecular weight. Accordingly, slope ratios in Figure 12 suggest that the Pee Dee aquifer has lower weight organics than the Castle Hayne aquifer, and that filtration pretreatment has negligible effect on Sr. Consistent with the FI results, the Sr values did not change after filtration. Sr for Castle Hayne second stage nanofiltration concentrate is unusually high, and may have been influenced by iron precipitation.



**Figure 10. Fluorescence index (FI) in Castle Hayne and Peedee waters at various levels of treatment. All samples were collected in August 2011, except for nanofiltration concentrate samples which were collected in September 2011.**



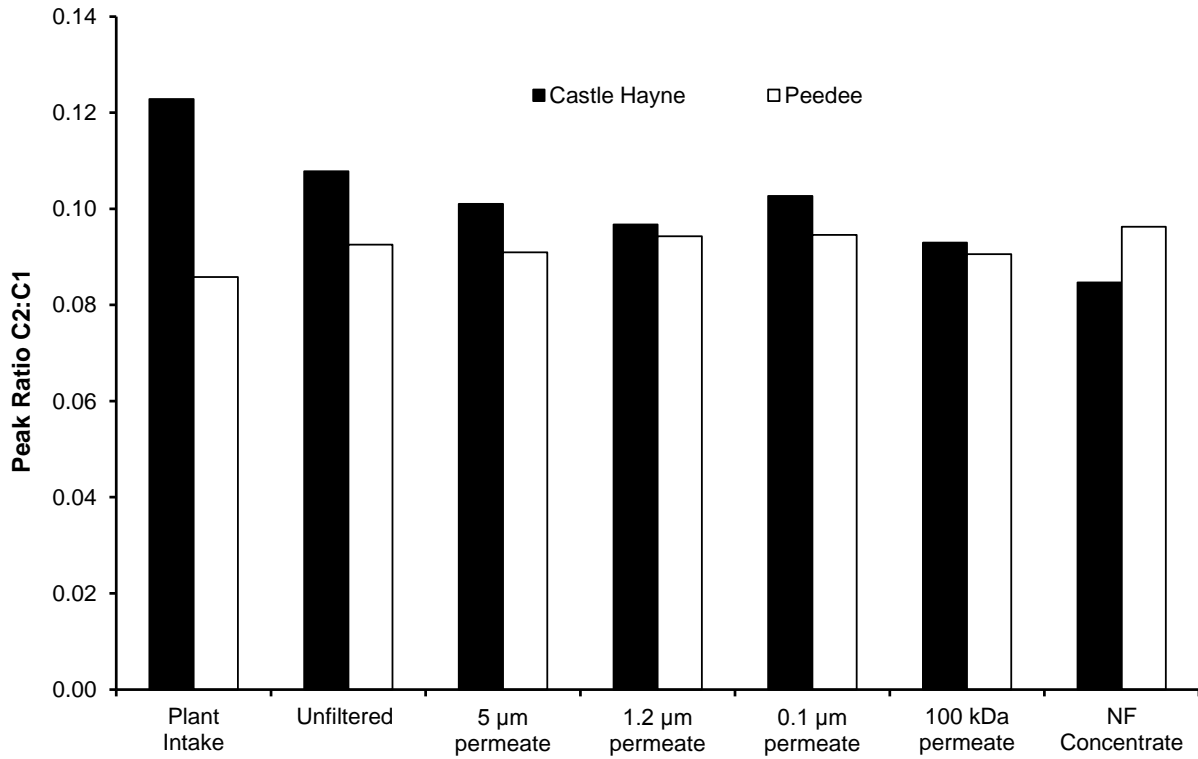
**Figure 11. Comparison of fluorescence index (FI) values in Castle Hayne and Peedee waters by type of filtration and sampling time. All samples were collected in 2011.**



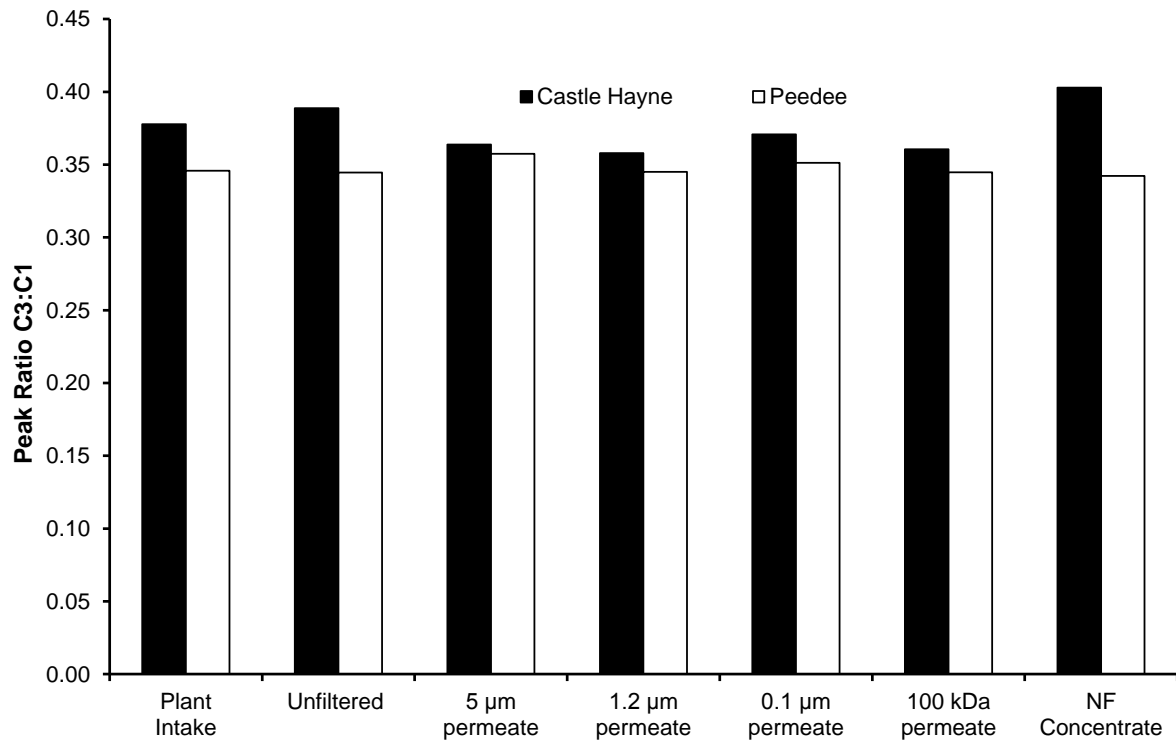
**Figure 12. Slope ratio(Sr) in Castle Hayne and Peedee waters at various levels of treatment.**

Caution should be used when making conclusions about molecular weight distributions based on fluorescence measurements when samples have high iron concentrations. Adding iron has been shown to aggregate organic matter, resulting in a shift from medium to high molecular weight organics (Pullin, 2007). The presence of iron may also increase UV absorbance(Weishaar, 2003) which would result in an elevated Sr. The influence of iron on fluorescence measurements for the Castle Hayne and Peedee waters will be further studied in the final report.

Changes in the ratios of fluorescence intensity of the three main fluorescence components as defined in Figure 8 can be used to study the preferential rejection of organic matter of varying origin. For example, if C1, C2 and C3 represent the fluorescence intensity for components 1, 2 and 3, respectively, a decrease of C2:C1 with a given treatment step would indicate a preferential rejection of component 2 over component 1. Given that component 1 (C1) is the most intense, it can be used to normalize the fluorescence of peaks C2 and C3. Accordingly, the ratios C2:C1 and C3:C1 have been plotted in Figures 13 and 14, respectively. The figures show that components 2 and 3 were not preferentially removed over component 1 by any filtration step for either Peedee or Castle Hayne water. The decrease in the C2:C1 ratio for the Castle Hayne water after water conditioning (i.e., “unfiltered” sample) may be related to the change of pH and iron content; this is the same water sample that showed a marked decrease in UVA after water conditioning in Figure 6. Additionally, the fluorescence intensity of the C1, C2 and C3 peaks do not change significantly, therefore indicating that DOC removed by filtration was not fluorescent.



**Figure 13. Ratio of peaks C2 to C1 in Castle Hayne and Peedee waters at various levels of treatment in samples collected in August 2011.**



**Figure 14. Ratio of peaks C3 to C1 in Castle Hayne and Peedee waters at various levels of treatment in samples collected in August 2011.**

## 5. Quality Control

As quality control, some water quality parameters measured at UNC were compared to the monthly averages measured at the plant of samples collected weekly by CFPUA. Turbidity, hardness, DOC, and conductivity were all comparable for the two laboratories as shown in Figure 15. The water quality of the aquifers is relatively variable on a monthly timescale as evidenced by the error bars from measurements at the plant. Water collected for bench-scale fouling tests will represent fouling potential at one discrete time. Water quality at the sampling time relative to annual averages will be taken into account when extrapolating bench-scale results to year-round operation.

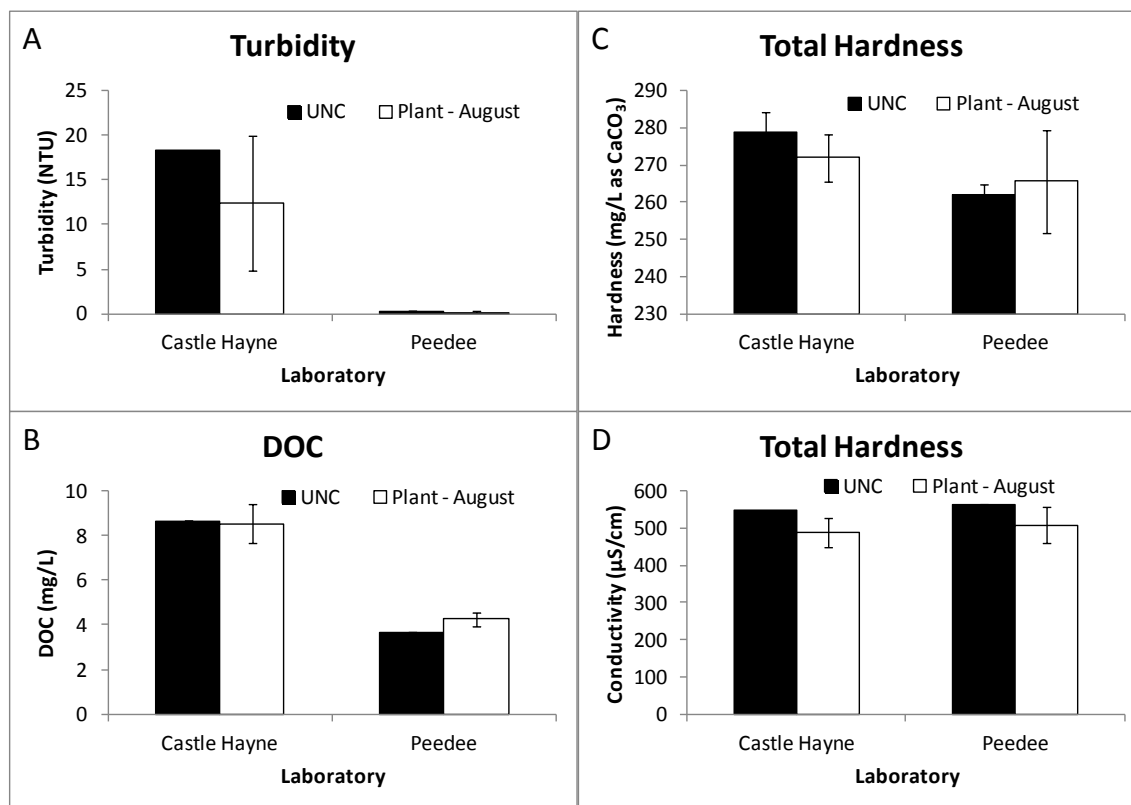
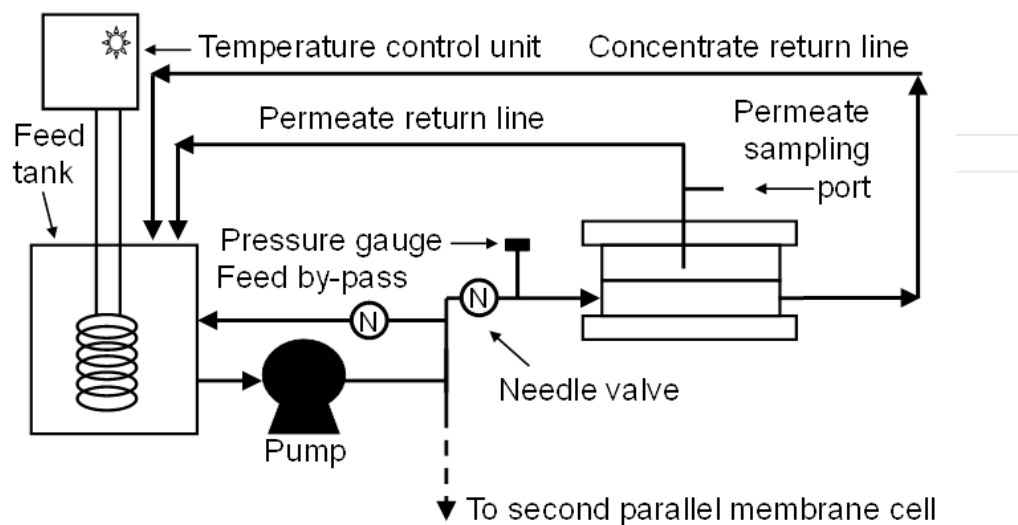


Figure 15. Comparison of (A) turbidity, (B) DOC, (C) total hardness, and (D) conductivity measured at UNC and by the Cape Fear Public Utility Authority (CFPUA). Averages from CFPUA are based on samples collected each Monday during the month of August. Samples analyzed by UNC were collected on August 18 with the exception of TOC, collected on September 18.

## 6. Description of Bench-Scale System

A schematic of the bench-scale membrane system built for the bench-scale fouling tests is shown in Figure 16. Feed water will be cooled to 10°C via a recirculating chiller. Feed water will then be pumped into two cross-flow membrane cells connected in parallel. Both the permeate and concentrate from the system will be recycled back to the reservoir. This allows for continuous operation of the membrane system under controlled laboratory conditions.



**Figure 16. Schematic of bench-scale membrane system.**

Figure 17 shows the completed bench-scale system. A 1/2 HP DC pump delivers 2.5 LPM of feed water at 150 psi. Membranes will be held in Osmonics SEPA cells (Minnetonka, MN) connected in parallel. Needle valves on the feed side allow for precise control of pressure and flow to each membrane cell. Given the length of the permeate return line, a sampling port was added next to the membrane cell to allow for rapid sample collection. In Figure 17, the sampling port is obscured by the pressure gauge in the feed line to the SEPA cells.



**Figure 17. Photo of bench-scale, cross-flow, flat-leaf, high-pressure membrane system.**

## 7. Deviation from Original Project Plans

Over the course of the project changes have occurred in: (1) the operation of the treatment plant, and (2) the availability of membranes from the manufacturer that provides the membranes to the plant. We describe below the changes that have taken place and how those changes have affected our research plan.

### 1) Change in the operation of the treatment plant

- Original situation: Treatment plant currently operates with two separate treatment trains, one train with Peedee water and one train with Castle Hayne water
- Modified situation: Treatment plant will operate within a month with one train of Peedee water and one train of mixed Peedee-Castle Hayne water
- Reason for the change: The plant needs to reduce total suspended solids in the discharge (concentrate) effluent of the treatment train that uses Castle Hayne water; the solution is to dilute the Castle Hayne water with Peedee water at the beginning of the treatment train
- Effects on project: We will not be able to collect raw Castle Hayne water for membrane fouling tests beyond the samples that we have already collected. We collected enough water to perform all tests; however, we are unsure of whether the relatively high iron levels of Castle Hayne water will cause precipitation or other changes in water quality during storage. If precipitation does occur, then we will need to replace the Castle Hayne water as test water for the new mixed Castle Hayne-Peedee water that the treatment plant will use.

Note: Please note that this change in the research plan is only potential and not certain, as it depends on the behavior of the Castle Hayne water during storage.

### 2) Change in availability of membranes material

- Original situation: Koch Membranes produced both TFC-S and TFC-ULP membranes which are the two membranes that are used in the treatment plant
- Modified situation: Koch Membranes is not producing TFC-S membranes and they have recently re-confirmed to us (Cangiano, 2011) that they do not know when they will re-start production; it will likely be after the end date of the project. (We first tried to buy the membranes in Summer 2011 and they were already not available at that time).
- Reason for the change: Koch Membranes mentioned changes in the location of the production plant and in the specifications of the TFC-S membrane modules.
- Effects on project:
  - a. Fouling, cleaning and autopsy tests were going to be performed in the lab with TFC-S and TFC-ULP membranes. Because of the unavailability of the TFC-S membrane, we will not be able to perform lab tests with the TFC-S membrane. We are interacting with Koch Membranes so that they advise what membrane would be the most appropriate replacement of TFC-S membranes.
  - b. Due to both the change in the operation of the treatment plant and current unavailability of TFC-S elements, it may not be possible to collect TFC-S elements from the Castle Hayne treatment train at the plant before the Castle Hayne water is replaced as feed water by the new mixed Castle Hayne-Peedee water. As a result, autopsy tests to membrane elements from this treatment train will likely reflect fouling from the mixed water and not from Castle Hayne water only.



3) The following important items are also worth mentioning:

- a. We have avoided additional changes to the research plan thanks to the generosity of the treatment plant which will do strategic changes in the distribution of membrane modules in the plant, and contribute funds (~\$2,500-\$3,000) to buy five more membrane modules in addition to the two modules that we budgeted in the proposal. (Malone, 2011)
- b. We have avoided additional changes to the research plan thanks to the generosity of Koch membrane in producing TFC-ULP modules specifically for us. TFC-ULP modules are also currently out of production. (Cangiano, 2011)
- c. We still expect to complete the project in the expected timeline, but with the changing situation in the operation of the treatment plant and in the availability of membranes, an eventual delay may occur. We will keep WRRI informed of any relevant changes.

## 8. Short-Term Plans

Particle size distribution measurements will be performed to complete water characterization. Further measurements as stated in Section 4 will also be made to compliment data related to group 1, 2 and 3 parameters. In particular, fluorescence measurements will be repeated with nanofiltration permeate from both treatment trains. Also, for unfiltered Castle Hayne water, UVA and FI will be measured again to determine if the results from August were outliers. Turbidity will also be measured at the treatment plant and at UNC to ascertain if turbidity increases during sample transport due to iron precipitation. The effect of sample transport on pH will also be determined through measurements at the plant and in the laboratory.

Upon receiving the TFC-ULP flat sheet membrane from Koch, we will begin bench-scale tests with water from the Castle Hayne Aquifer. Autopsy tests will then be performed on bench-scale samples and elements collected from the treatment plant. Once foulants have been characterized by autopsy tests, bench-scale cleaning studies will be conducted.

## References

- American Public Health Association (APHA); American Water Works Association (AWWA); Water Environment Federation (WEF). *Standard Methods for the Examination of Water and Wastewater*; 18 ed.; American Public Health Association: Washington, D.C., 2006.
- Amy, G. (2008). Fundamental understanding of organic matter fouling of membranes. *Desalination*, 231(1-3), 44-51
- Benjamin, M. M. (2002). *Water Chemistry*. Long Grove, IL: Waveland Press, Inc.
- ASTM Standard D4189, 1995 (2002), "Silt Density Index (SDI) of Water," ASTM International, West Conshohocken, PA, 2002.
- Cangiano, J., *Personal communication*. 2011, Koch Membrane Systems.
- Fluid Systems TFC-S 8" Elements-Data Sheet*. 2010, Koch Membrane Systems.
- Fluid Systems TFC-ULP 8" Elements-Data Sheet*. 2010, Koch Membrane Systems.
- Helms, J. R., Stubbins, A., Ritchie, J. D., Minor, E. C., Kieber, D. J., & Mopper, K. (2008). Absorption spectral slopes and slope ratios as indicators of molecular weight, source, and photobleaching of chromophoric dissolved organic matter. *Limnology and Oceanography*, 53(3), 955-969.
- Her, N., Amy, G., & Jarusutthirak, C. (2000). Seasonal variations of nanofiltration (NF) foulants: identification and control. *Desalination*, 132(1-3), 143-160
- Kavitha, a L., Vasudevan, T., & Prabu, H. G. (2011). Evaluation of synthesized antiscalants for cooling water system application. *Desalination*, 268(1-3), 38-45
- Kumar, M., S. S. Adham and W. R. Pearce (2006). "Investigation of seawater reverse osmosis fouling and its relationship to pretreatment type." *Environmental Science & Technology* 40(6), 2037-2044.
- Malone, J.; Colon, A., *Personal communication*. 2011, North Carolina Cape Fear Public Utility Authority.
- Pullin, M. J., Anthony, C., & Maurice, P. a. (2007). Effects of Iron on the Molecular Weight Distribution, Light Absorption, and Fluorescence Properties of Natural Organic Matter. *Environmental Engineering Science*, 24(8), 987-997
- Schafer, A. L., Fane, A. G., & Waite, T.D. (2006). *Nanofiltration: Principles and Applications*. Oxford, UK: Elsevier Advanced Technology.

- Shipko, F. J., Douglas, D.L. (1956). Stability of Ferrous Hydroxide Precipitates. *Journal of Physical Chemistry*, 60, 1519-1523.
- United States Environmental Protection Agency, Office of Water. *Membrane Filtration Guidance Manual*, 2005.
- Weishaar, J. L., Fram, M. S., Fujii, R., Mopper, K., & Aiken, G. R. (2003). Evaluation of Specific Ultraviolet Absorbance as an Indicator of the Chemical Composition and Reactivity of Dissolved Organic Carbon. *Environmental Science & Technology*, 37(20), 4702-4708.
- Yoon, J., Yoon, Y., Amy, G., & Her, N. (2005). Determination of Perchlorate Rejection and Associated Inorganic Fouling (Scaling) for Reverse Osmosis and Nanofiltration Membranes under Various Operating Conditions. *Journal of Environmental Engineering*, 131(5), 726-733
- Zhu, A., Long, F., Wang, X., Zhu, W., & Ma, J. (2007). The negative rejection of  $H^+$  in NF of carbonate solution and its influences on membrane performance. *Chemosphere*, 67(8), 1558-65

## **Appendix 1. Alphabetical List of Abbreviations and Symbols with Definitions**

$\mu\text{S}/\text{cm}$  – Microsiemens per centimeter: Unit of resistance used in measuring conductivity (i.e. higher resistance, lower conductivity).

$\mu\text{m}$  – Micrometers

CFPUA – Cape Fear Public Utility Authority

DOC – Dissolved organic carbon: Mass concentration of organic carbon that passes a 0.45  $\mu\text{m}$  filter (see TOC).

DC – Direct current

EEMs – Excitation-emission matrices

FI – Fluorescence index

HP – Horsepower

ICP-MS – Inductively coupled plasma mass spectroscopy

kDa – Kilodalton. A unit of molecular weight, one Dalton is the average mass of one proton or neutron.

LPM – Liters per minute

NOM – Natural organic matter

NTU – Nephelometric turbidity unit: a measure of light-scattering particles in a sample.

PSI – Pounds per square inch

SDI – Silt density index

SUVA – Specific Ultraviolet Absorbance: ultraviolet absorbance (see UVA) divide by TOC.

TOC – Total organic carbon: Mass concentration of organic (i.e., cannot be removed by pH adjustment) combustible carbon.

UVA – Ultraviolet absorbance: absorbance of ultraviolet light with a wavelength of 254 nm.

## **Appendix 2. Publications, Patents, and Technology Transfer**

### **A2.1. Publications and Presentations**

No publications or presentations to date. Upon completion this research will become the Masters technical report of the graduate research assistant working in the project, and will be submitted to scholarly journals for publication. Results will also be submitted to conferences for presentation including the North Carolina WRI conference.

### **A2.2. Patents, Data Sets, or Web Sites**

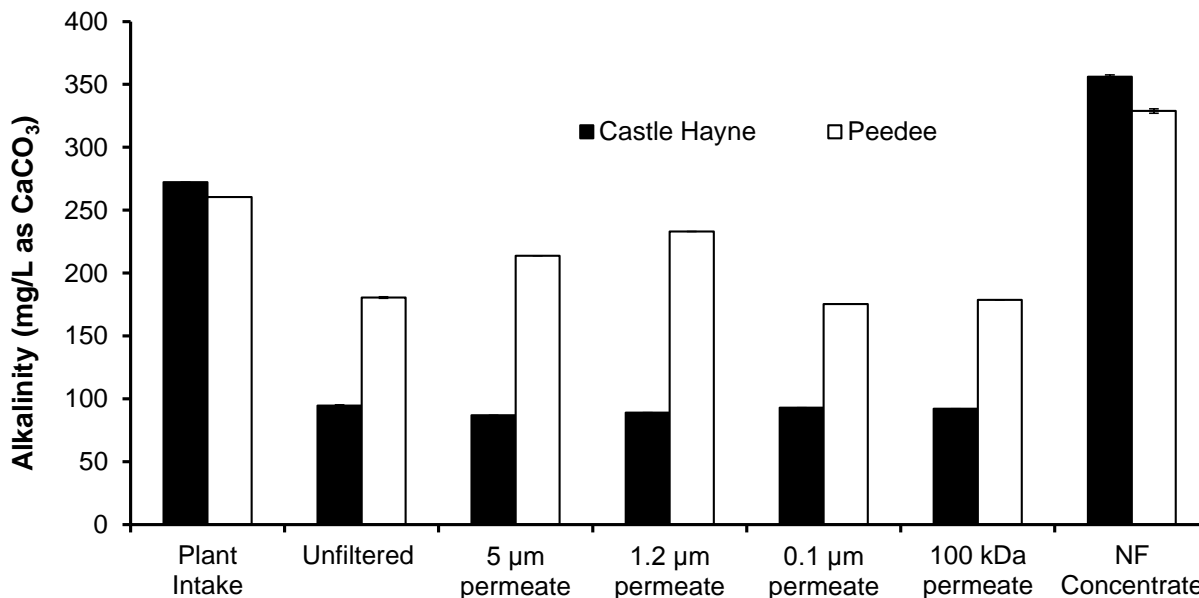
No patents, data sets, or web sites to date.

### **A2.3. Technology Transfer**

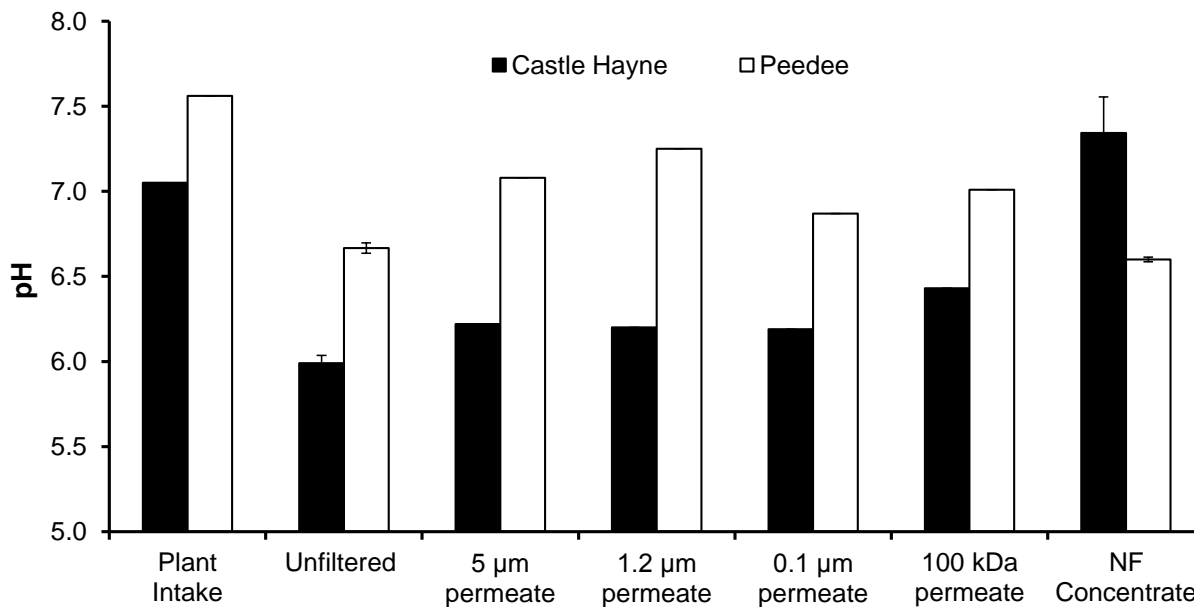
During the execution of this project there is permanent communication with the supervisor and operator of the groundwater nanofiltration CFPWA treatment plant. Water quality results have been discussed with them. Upon completion of the project, results and recommendations will also be shared with the plant personnel.

### Appendix 3. Additional Results for Group 2 Parameters

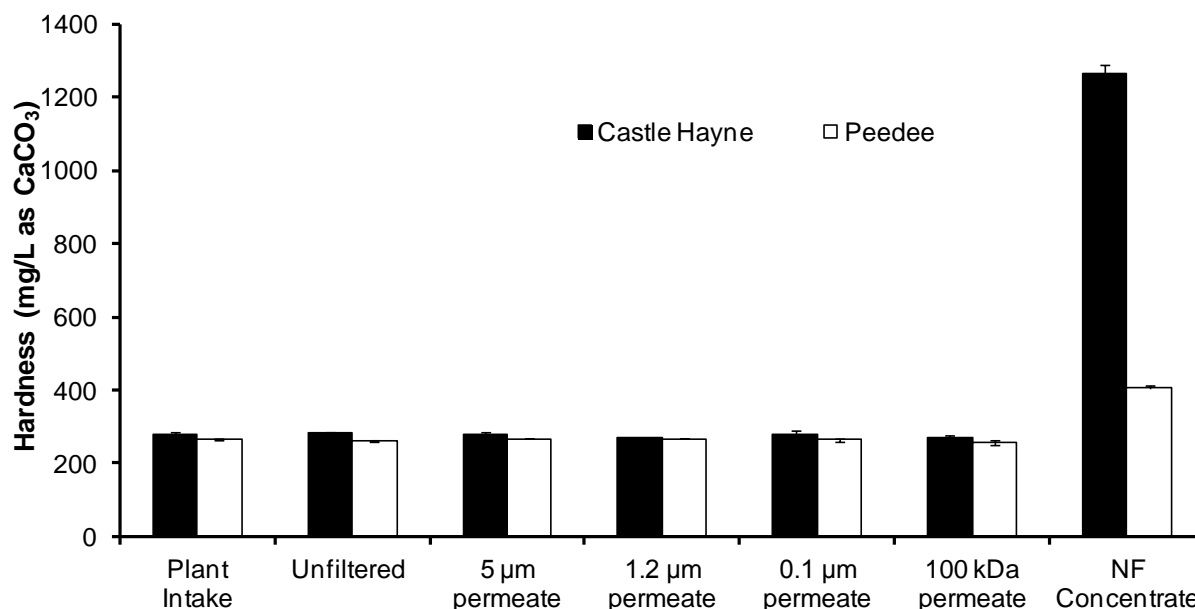
Alkalinity, pH, hardness, and conductivity are shown in Figure A3-1 through Figure A3-4, respectively. Although these parameters do not represent foulants, they are used in calculating precipitation potential of other compounds.



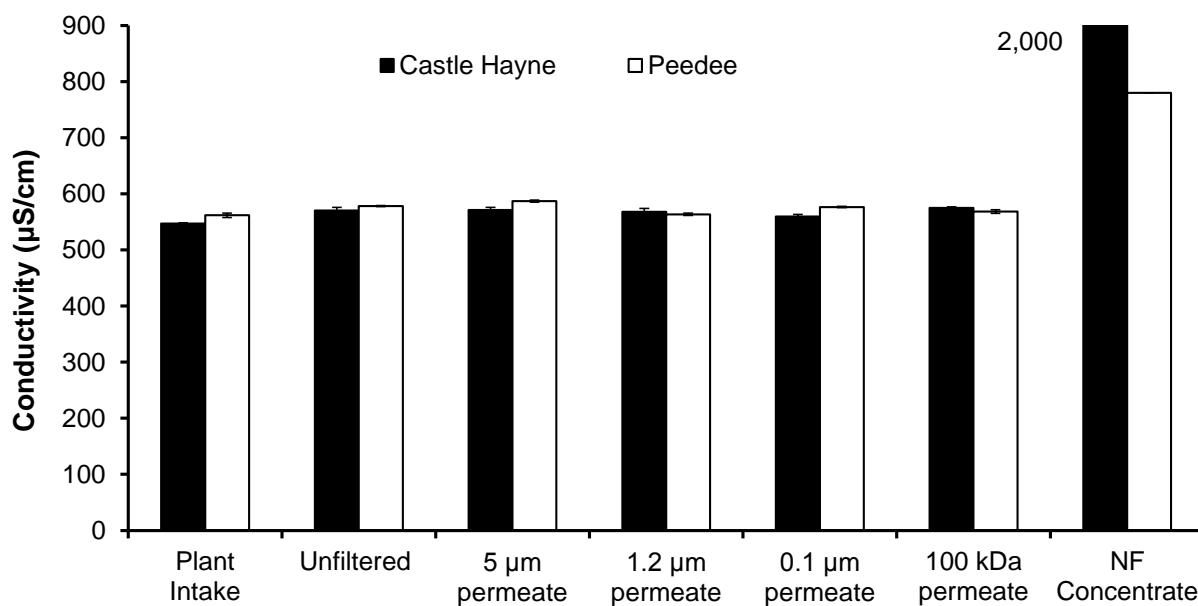
**Figure A3-1. Alkalinity in Castle Hayne and Peedee waters. All samples were collected in August 2011, except for membrane concentrate from both aquifers which were collected in September 2011.**



**Figure A3-2. pH in Castle Hayne and Peedee waters. All samples were collected in August 2011, except for membrane concentrate from both aquifers which were collected in September 2011.**

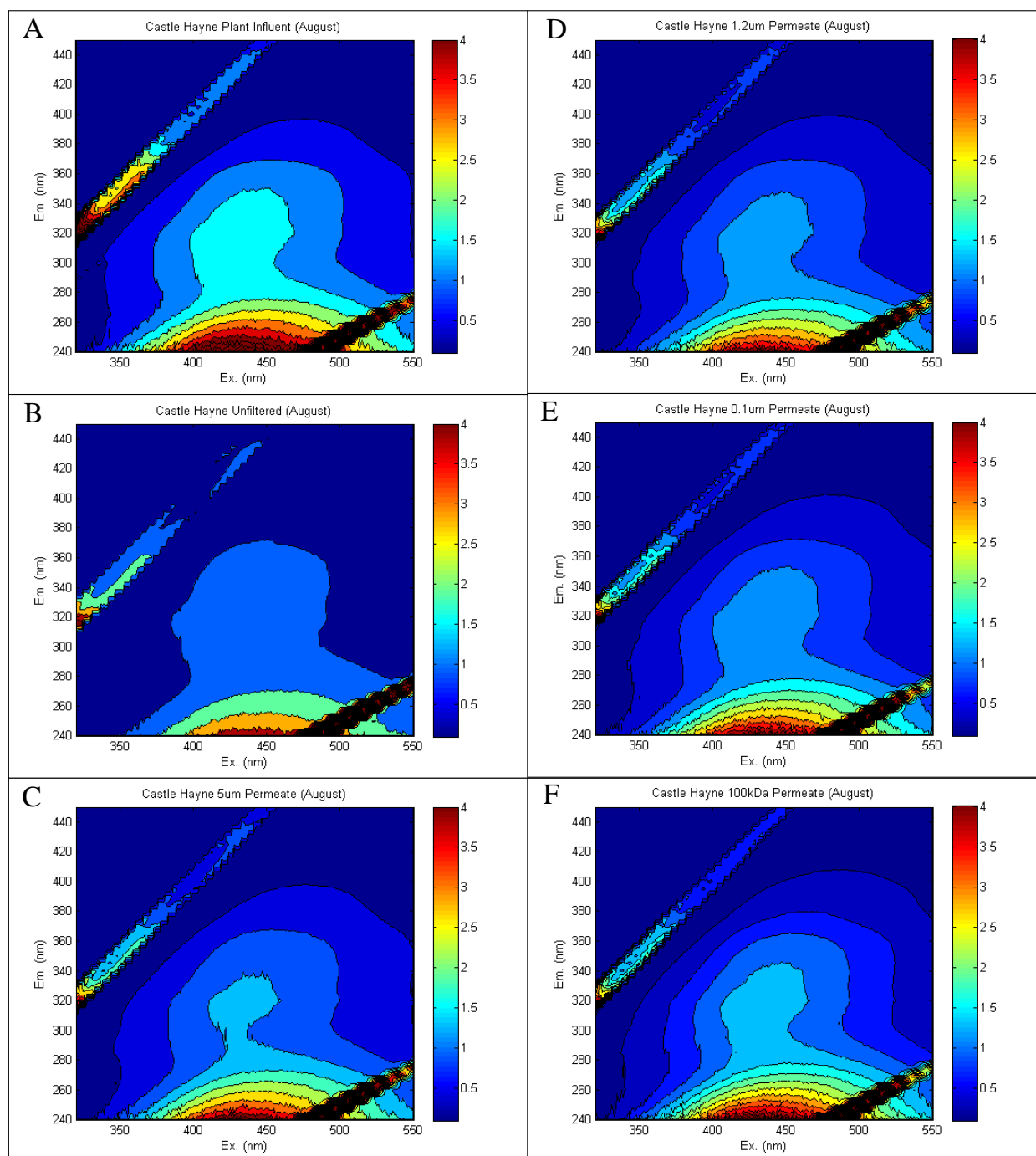


**Figure A3-3. Hardness in Castle Hayne and Pee Dee waters. All samples were collected in August 2011, except for membrane concentrate from both aquifers which were collected in September 2011.**



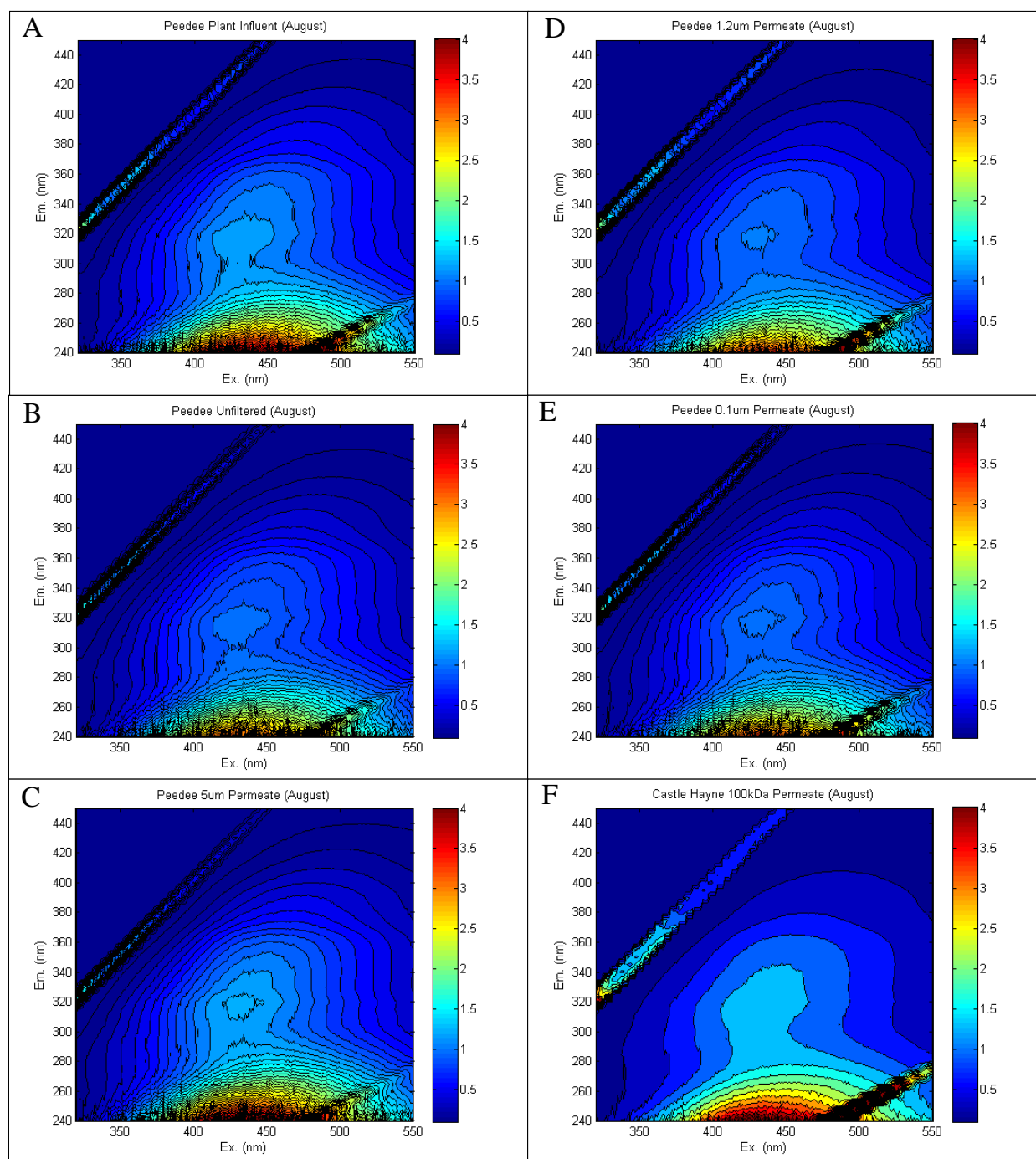
**Figure A3-4. Conductivity in Castle Hayne and Pee Dee waters. All samples were collected in August 2011, except for membrane concentrate from both aquifers which were collected in September 2011. Castle Hayne concentrate had much higher conductivity than other samples, with 2,000 mS/cm.**

## Appendix 4. Additional Results for Group 3 Parameters

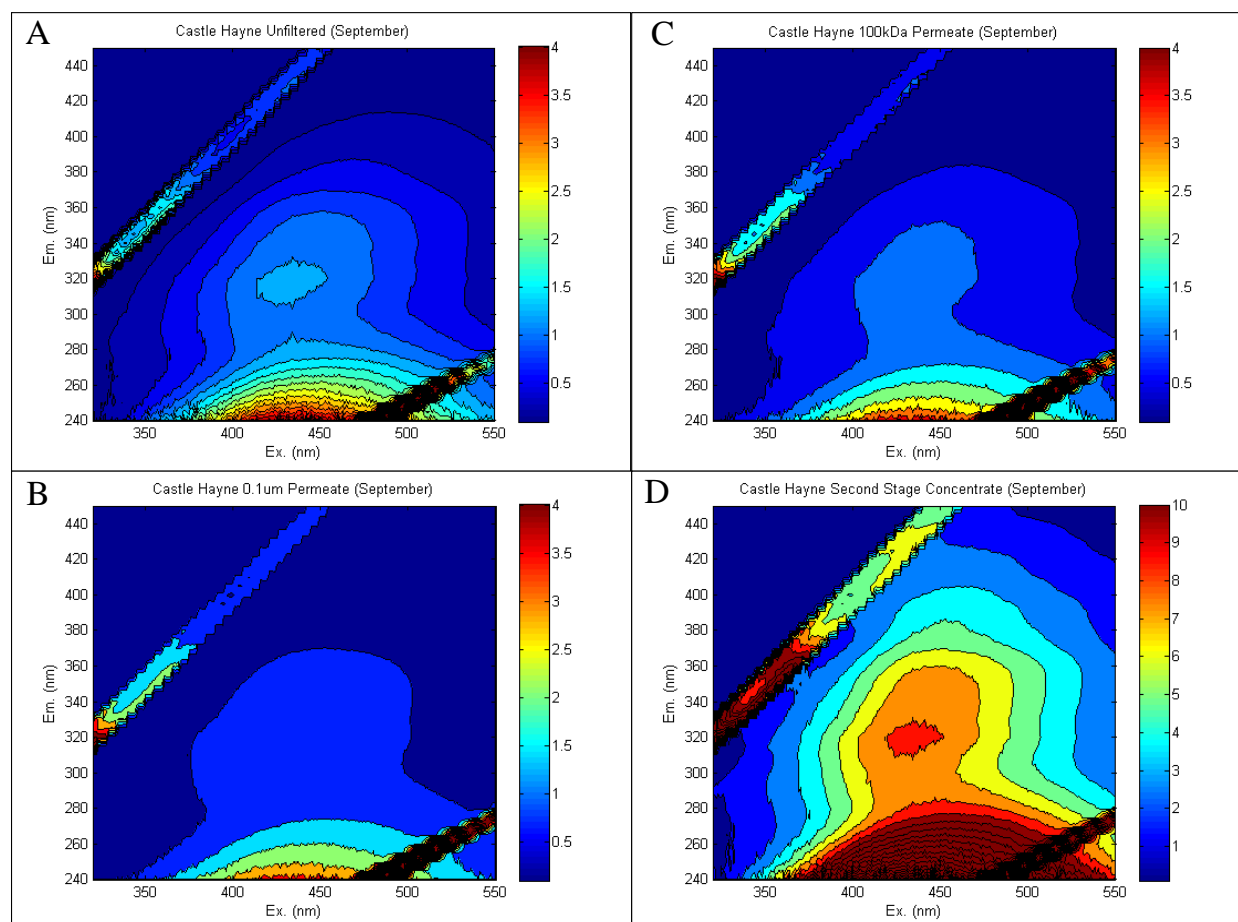


**Figure A4-1. Excitation-Emission Matrices (EEMs) for samples collected from the Castle Hayne treatment train in August 2011. Samples include (A) plant influent, (B) influent after pH adjustment and anti-scalant addition, (C) 5um cartridge filter effluent, (D) 1.2um filter effluent, (E) 0.1um filter effluent, and (F) 100kDa filter effluent. For C through F, filtration tests were performed in the UNC laboratories using B as influent.**

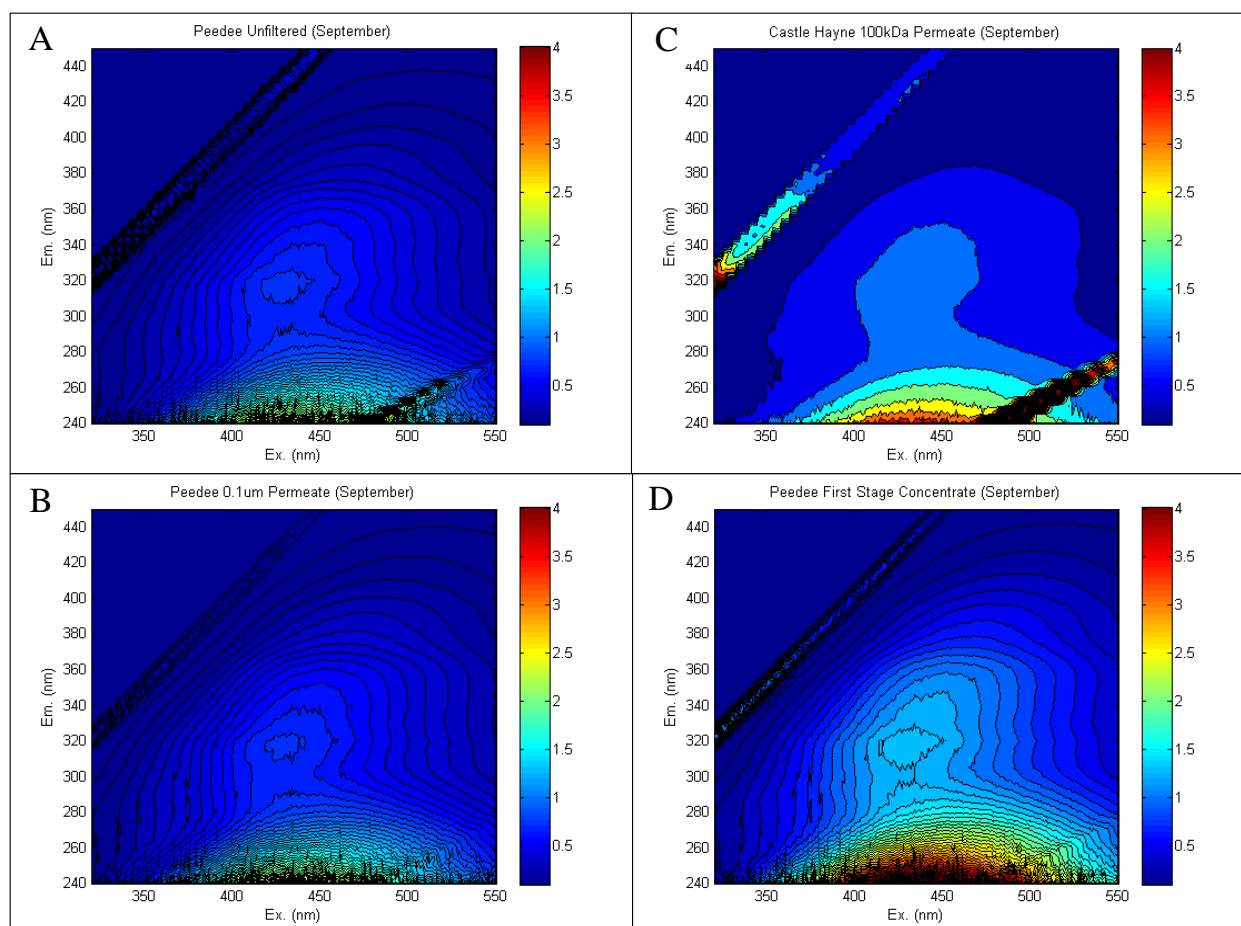




**Figure A4-2. Excitation-Emission Matrices (EEMs) for samples collected from the Pee Dee treatment train in August 2011. Samples include (A) plant influent, (B) influent after pH adjustment and anti-scalant addition, (C) 5um cartridge filter effluent, (D) 1.2um filter effluent, (E) 0.1um filter effluent, and (F) 100kDa filter effluent. For C through F, filtration tests were performed in the UNC laboratories using B as influent.**



**Figure A4-3. Excitation-Emission Matrices (EEMs) for samples collected from the Castle Hayne treatment train in September 2011. Samples include (A) influent after pH adjustment and anti-scalant addition, (B) 0.1um filter effluent, (C) 100kDa filter effluent, and (D) second stage membrane concentrate. For B and C, filtration tests were performed in the UNC laboratories using A as influent. Note that panel E has a different scale than A-C.**



**Figure A4-4. Excitation-Emission Matrices (EEMs) for samples collected from the Peedee treatment train in September 2011. Samples include (A) influent after pH adjustment and anti-scalant addition, (B) 0.1um filter effluent, (C) 100kDa filter effluent, and (D) first stage membrane concentrate. For B and C, filtration tests were performed in the UNC laboratories using A as influent.**

## Information Transfer Program Introduction

The Water Resources Research Institute (WRRI) is heavily focused and geared to providing water resources information to the water professional. WRRI maintains a strong information transfer program by cooperating with various state agencies, municipalities, and professional organizations to sponsor workshops and other events and by seeking grants for relevant activities.

The professionals targeted by this program include private entrepreneurs, federal, state and local government staff and officials, and representatives of industry, agriculture, consulting, and environmental groups. The main forms of information transfer are through an Institute internet site, bi-monthly newsletter, conferences, seminars, forums, workshops, luncheons, and research publications.

The workshops conducted through WRRI's partnership with the Department of Environment and Natural Resources Division of Land Resources constitute the primary means by which the Division meets its educational obligations on sediment control under the state's Sedimentation Control Act.

WRRI continues to be a sponsor of continuing education credits by the NC Board of Examiners of Engineers and Surveyors as an Approved Sponsor of Continuing Professional Competency activity for Professional Engineers and Surveyors licensed by the State of North Carolina. In addition, WRRI also submits information for approval to the N.C. Board of Landscape Architects to offer contact hours to landscape architects. This allows WRRI to offer Professional Development Hours (PDHs) to engineers and surveyors, and Continuing Education Units (CEUs) to landscape architects for attendance at the WRRI Annual Conference and other workshops, seminars and forums that WRRI sponsors.

During this reporting year, WRRI provided 91 PDHs and 73.25 CEUs to 1265 people at 16 workshops, seminars, and other events described below.

## WRRRI Information Transfer Program

### Basic Information

<b>Title:</b>	WRRRI Information Transfer Program
<b>Project Number:</b>	2011NC162B
<b>Start Date:</b>	3/1/2011
<b>End Date:</b>	2/29/2012
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	NC-02
<b>Research Category:</b>	Not Applicable
<b>Focus Category:</b>	None, None, None
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	Nicole Wilkinson

### Publications

1. Gray, Jeri, 2011, WRRRI News Newsletter April-June 2011, ISSN 0549-799X, Issue 374, 20pp
2. Gray, Jeri, 2011, WRRRI News Newsletter July-September 2011, ISSN 0549-799X, Issue 375, 13pp
3. Gray, Jeri, 2011, WRRRI News Newsletter October-December 2011, ISSN 0549-799X, Issue 376, 12pp
4. Gray, Jeri, 2012, WRRRI News Newsletter January-March 2012, ISSN 0549-799X, Issue 377, 8pp

## **FY 2011 Information Transfer Progress & Achievements**

### **Newsletter**

Published the *WRRRI News* four times during the reporting period (April-June 2011 Issue #374, July-Sept 2011 Issue #375, Oct-Dec 2011 Issue #376 and Jan-Mar Issue #377) The WRRRI News is an 8-12 page newsletter that covers a wide range of water-related topics from current federal and state legislation and regulatory activities to new research findings, water-related workshops and conferences, and reviews of water-related publications. The WRRRI News is now sent electronically to 963 federal and state agencies, university personnel, multi-county planning regions, city and local officials, environmental groups, consultants, businesses and individuals. It is also posted on the WRRRI website <http://www.ncsu.edu/wrri/code/publications/currentpublications.htm>

### **Internet Services**

In fall 2011, the Water Resources Research Institute of The University of North Carolina launched a brand new website ([www.ncsu.edu/wrri](http://www.ncsu.edu/wrri)). The new site was designed by Ms. Pam Conrad, a Raleigh NC based web consultant. The goals of the new site were to provide more streamlined access to information related to WRRRI events, research, publications, key partners, and the background and mission of WRRRI at the state and national levels. Since launching the site, WRRRI has received extremely positive feedback from constituents and partners alike. Between June 2011 (which is the earliest date we have web statistics for) and February 2012, the site received 271, 992 hits. The new website is accountable for 70656 of those hits over the three months in this reporting period that it was active.

A related component of the new website involved working with NC State University's DH Hill Library to increase and enhance WRRRI's use of their technical reports repository for all WRRRI publications. Through this collaboration, we are now able to direct people to this well organized, easily searchable site where they can access research reports from all WRRRI-funded projects as far back as the 1960s. While the repository was operational before, the new website's dedicated publications page helps to make better use of it.

Overall, the goals of our website are:

- to provide access to information on upcoming events (seminars, workshops, etc) that are hosted by WRRRI and other events in the state related to water resources, as well as access to materials and resources from past events;
- to provide information to the research community about funding opportunities and state research priorities;
- to increase dissemination of information by providing access to research reports, the WRRRI newsletter, and other relevant publications;

- to provide information on key organizations with which WRRI has strong partnerships and which play a key role in water resource research and management in the state;
- to provide background information about WRRI at the state and federal levels, our roles, and what we can offer to different audiences throughout the state.

### **WRRI Electronic Lists**

WRRI maintains the following electronic mail lists (listservs) for information transfer purposes:

- Water-Research list - 208 subscribers – inform water researchers from NC universities about calls for papers, grants, upcoming conferences, student internships, etc.;
- WRRI-News list - 963 subscribers - informs researchers, local governments, municipalities, interest groups etc. about calls for papers, grants, upcoming conferences and events, etc.;
- NCWRA-info list - 246 subscribers - provides information of the North Carolina Water Resources Association sponsored events;
- Urban Water Consortium (UWC) for Urban Water Consortium member communications;
- and UWC-Stormwater Group list for the UWC Stormwater Group member communications.

### **Audio-Visual Productions**

The Water Resources Research Institute designed a tabletop exhibit to display at conferences, workshops, and other events in which we participate. The exhibit is a 7' x 4', 4-panel display. This display was recently updated to highlight what WRRI offers to different audiences around the state, provide conversation starters regarding careers in water resources, and connects people and their land-based activities to downstream impacts to water resources.

Most presentations given at workshops and seminars sponsored by WRRI are uploaded to the WRRI website for public viewing (see under WRRI Internet Services). Researchers and their students supported by WRRI funds often participate in the annual conference by giving an oral or poster presentation, and these are also available on the WRRI website.

### **NC Urban Water Consortium**

WRRI administers the NC Urban Water Consortium (UWC) and meets with the members quarterly. The consortium was established in 1985 by the Institute, in cooperation with several of North Carolina's larger cities to provide a program of research and development, and technology transfer on water problems that urban areas share.

Through this partnership, WRRRI and the State of North Carolina help individual facilities and regions solve problems related to local environmental or regulatory circumstances. Participants support the program through annual dues and enhancement funds and guide the program through representation on an advisory board, selection of research topics, participation in design of requests for proposals, and review of proposals. There are 12 member cities/special districts in North Carolina, and several members hosted quarterly meetings on the following dates: March 18, 2011 in High Point; June 17, 2011 in Fayetteville; September 23 in Winston Salem; and December 16, 2011 in Burlington.

The UWC also provided full support to three research projects, which increased WRRRI's ability to fund other high quality research with 104(b) funds. The three projects funded by the UWC were:

- “Experimental Reservoir Storage Forecasts Utilizing Climate-Information Based Streamflow Forecasts” by PI Sankar Arumugam, NC State University
- “Shifting Baselines in Water Utility Management: New Tools for Addressing Financial Impacts of System Transitions” by PI Jeff Hughes, UNC-Chapel Hill
- “Microbial Risk Assessment of Graywater Reuse using Quantitative Molecular Approaches” by PI Francis de los Reyes, NC State University

#### **NC Urban Water Consortium - Stormwater Group**

In 1998, several members of the NC UWC partnership formed a special group to sponsor research and technology transfer on issues related to urban stormwater and management. The Urban Water Consortium (UWC) Stormwater Group is administered by WRRRI. Participants support the program through annual dues and enhancement funds. They guide the program through selective representation on the WRRRI advisory board, determining stormwater-related research priorities, participation in the design of requests for proposals and review of proposals submitted to WRRRI directly or to the SWG. During this reporting year, the SWG added their ninth member, the City of Burlington, to their membership. Quarterly meetings were held on the following dates: March 10, 2011 in Durham; June 16, 2011 in Fayetteville; September 14, 2011 in Wilmington; and December 16, 2011 in Burlington.

The UWC-SWG provided funding for a project “Evaluating Restoration Success in the Watershed Context” by PI Sandra Clinton at UNC-Charlotte.

#### **Other WRRRI Sponsored Workshops, Forums and Seminars**

Below is a list of the educational and training events WRRRI sponsored during the project year, along with a description of each and the number of attendees.

#### **March 8-9, 2011 Erosion and Sedimentation Control Planning and Design Workshop**

*Description:* These workshops are structured to educate and familiarize design professionals with the NC Sedimentation Pollution Control Act (SPCA), the rules implementing the Act, design standards for erosion and sedimentation control BMPs,



and elements that are necessary to submit an erosion control plan. This comes directly from the source—the NC Division of Land Resources Land Quality Section and its partners to provide professionals with the information they need to submit an erosion control plan and prevent pollution by sedimentation. The first day of this workshop focused on how to control turbidity on construction sites and included a field exercise. The second day focused on new rules and design standards that will affect those conducting land disturbing activities.

*Attendance:* 50

**March 22-23, 2011 WRRRI Annual Conference "Exploring Water Resources Needs, Benefits and Services in North Carolina" and NCWRA Symposium "Implementing the Falls Lake Nutrient Management Strategy: Challenges and Opportunities"**

*Description:* Exploring Water Resources Needs, Benefits and Services in North Carolina was the focus of the 2011 Water Resources Research Institute Annual Conference – North Carolina’s premier water research conference. The conference addressed a suite of topics such as services that aquatic ecosystems provide to human, plant, and animal communities, management practices aimed at ensuring sustainability of these resources and their services, and other research, regulations, needs and opportunities related to our state’s water resources. The NC Water Resources Association was again a key partner, with the NCWRA Annual Symposium being an integral element of the conference program. The symposium, “Implementing the Falls Lake Nutrient Management Strategy: Challenges and Opportunities”, focused on the implications of one of the most ambitious nutrient management strategies ever advanced by a state, which has far-reaching implications for the management and development of land and water resources in existing and future communities. The conference offered 9.5 PDHs, 9.5 CEUs, and had 210 attendees. Over a 2-day period, the conference featured 111 presentations – 64 oral presentations over 16 concurrent sessions, 15 invited speakers in special sessions, and 32 poster presentations.

*Attendance:* 210

**March 23, 2011 Progress Energy Seminar "Smaller is Better: Watershed Work in North Carolina (WWINC)**

*Description:* This seminar explored tools and resources used in watershed planning, explored methods for assessing and prioritizing watersheds for restoration work, and examined local case studies of watershed work in North Carolina.

*Attendance:* 150

**April 5-6, 2011 Erosion and Sedimentation Control Planning and Design Workshop**

*Description:* These workshops are structured to educate and familiarize design professionals with the NC Sedimentation Pollution Control Act (SPCA), the rules implementing the Act, design standards for erosion and sedimentation control BMPs, and elements that are necessary to submit an erosion control plan. This comes directly from the source—the NC Division of Land Resources Land Quality Section and its partners to provide professionals with the information they need to submit an erosion

control plan and prevent pollution by sedimentation. The first day of this workshop focused on how to control turbidity on construction sites and included a field exercise. The second day focused on new rules and design standards that will affect those conducting land disturbing activities.

*Attendance:* 54

**May 2, 2011 NCWRA Seminar "Whose Water Is It? Issues in a Recent Interbasin Transfer Approval and Implications for Interstate Water Management"**

*Description:* Transfers of water between river basins occur regularly and are regulated in North Carolina. Such transfers are frequently a product of our state's development history - we have tended to build large settlements along railways, and railways typically follow ridgelines. Along with our geographic tendency to transfer large amounts of water from one river basin to another, we have a tendency to argue publicly over such interbasin transfers. Some of those arguments cross state boundaries, as well as river basin boundaries. A past example of such an interstate, interbasin transfer controversy is Virginia Beach and Lake Gaston. The most recent example is the Catawba River Water Supply Project. On December 3, 2010, the States of North Carolina and South Carolina, Duke Energy Carolinas, and the Catawba River Water Supply Project settled their disagreement of the interbasin transfer that North Carolina had approved. This forum consisted of a panel of speakers who were integral to the resolution of the Catawba River Basin case and are well positioned to discuss its details and implications for water resources management in North Carolina.

*Attendance:* 41

**May 9, 2011 DWQ Riparian Buffers and Coastal Stormwater Workshop**

*Description:* These workshops were developed to educate design professionals on North Carolina's stormwater programs and its stream, wetland and riparian buffer rules. Attendees learned about pertinent regulations, application processes and program updates directly from Division of Water Quality staff.

*Attendance:* 83

**September 19, 2011 NCWRA Seminar, "The Dirt on the Dirt: What You Need to Know About the New Construction Site Runoff Guidelines"**

*Description:* The US EPA is implementing a national Effluent Limit Guideline for construction site runoff which will have a maximum turbidity limit far below what is typically discharged using current practices. How are we going to stay in compliance without breaking the bank? The basic principles of Passive Treatment Systems to do this were discussed along with a number of case studies from actual construction sites.

*Attendance:* 92

**October 10, 2011 Water System Auditing and Loss Control Workshop**

*Description:* Frustrated with utility expenses outpacing revenues with utility customers being upset that they are being asked to conserve, while perceiving they are paying for a water system's inefficiencies has prompted water utilities to take action. Best-practices

for Water Auditing and Loss Control, as developed by the American Water Works Association, are beginning to take hold among water systems in the Southeast and across the nation. Water Auditing and Loss Control programs are the most effective ways for a utility to conserve water, save operating expenses, and increase revenues. The State of Georgia now requires Water Auditing from its public water utilities, and policymakers in Kentucky, Tennessee and Virginia are considering the Georgia model. In North Carolina over 30 systems have recently embraced these best-practices for Water Auditing and Loss Control, and the results are compelling. To further NC's knowledge in this area, we brought together the operational, financial and regulatory perspectives to present the state of water efficiency in the industry, and where it goes from here. Presentations included lessons learned from other NC utilities over the short-term, systems outside NC over the long-term, funding options for performing audits, and a look at the regulatory momentum in the Southeast. A demonstration on the AWWA Free Water Audit Software was also included.

*Attendance:* 102

#### **October 14, 2011 Water Paradigm Seminar "A Fundamental Change in Managing Our Community Water Infrastructure"**

*Description:* In recent years many experts and practitioners have come to the conclusion that we must fundamentally change the way we conduct business with regard to our water, wastewater and stormwater infrastructure and operations if we are to successfully overcome the many challenges that our communities are facing or will likely face in this 21st Century. Some of the greater challenges include aging infrastructure and the gap in our financial resources to maintain properly or replace it, increases in impaired waters in our communities that drive regulatory responses, impacts of changing patterns in drought and wet weather, the need to reduce energy consumption for water-related infrastructure and more. Mr. Trevor Clements of Tetra Tech, Inc. discussed research on defining a new paradigm for water management sponsored by the Water Environment Research Foundation and the Electric Power Research Institute.

*Attendance:* 30

#### **October 25-26, 2011 Erosion and Sedimentation Control Planning and Design Workshop**

*Description:* This workshop was structured to educate and familiarize design professionals with the NC Sedimentation Pollution Control Act (SPCA), the rules implementing the Act, design standards for erosion and sedimentation control BMPs, and elements that are necessary to submit an erosion control plan. This comes directly from the source—the NC Division of Land Resources Land Quality Section and its partners to provide professionals with the information they need to submit an erosion control plan and prevent pollution by sedimentation.;

*Attendance:* 64

#### **November 9-10, 2011 Erosion and Sedimentation Control Planning and Design Workshop**

*Description:* This workshop was structured to educate and familiarize design professionals with the NC Sedimentation Pollution Control Act (SPCA), the rules implementing the Act, design standards for erosion and sedimentation control BMPs, and elements that are necessary to submit an erosion control plan. This comes directly from the source—the NC Division of Land Resources Land Quality Section and its partners to provide professionals with the information they need to submit an erosion control plan and prevent pollution by sedimentation.;  
*Attendance:* 114

**December 5, 2011 NCWRA Seminar, "Program Changes at the Ecosystem Enhancement Program"**

*Description:* In February of 2011 the North Carolina Ecosystem Enhancement Program (EEP) began a series of operational and organizational changes that are transforming the way EEP develops mitigation in North Carolina. More changes are on the way to comply with Session Law 2011-343. This presentation provided up to date information on EEP including changes in project procurement and watershed planning processes, development of tools to strengthen the connection between restoration projects and watershed functional improvement, and establishment of a Science Advisory Panel.  
*Attendance:* 90

**December 9, 2011 DWQ 401, Riparian Buffer and Nutrient Management Strategy Workshop**

*Description:* This workshop was developed to educate design professionals on North Carolina's stormwater programs and its stream, wetland and riparian buffer rules. Attendees learned about pertinent regulations, application processes and program updates directly from Division of Water Quality staff.  
*Attendance:* 124

**January 19, 2012 Water Audit Software Training**

*Description:* Best-practices for Water Auditing and Loss Control, as developed by the American Water Works Association, are beginning to take hold among water systems in the Southeast and across the nation. Water Auditing and Loss Control programs are the most effective ways for a utility to conserve water, save operating expenses, and increase revenues. To this end, the AWWA Water Loss Control Committee has made available a free software application as a useful and easy way for utilities to compile a basic, preliminary audit of water supply and billing operations, and begin to measure key performance indicators for water system efficiency. This workshop helped participants learn how to use the software, gain a thorough understanding of the data inputs and data validity, and understand software outputs and how to apply them to your utility. Participants will benefit from team work, paper exercises, computer work, and a small amount of lecture, and will learn using real and simulated data from large and small utilities.  
*Attendance:* 24

**February 1-2, 2012 Local Programs Erosion and Sedimentation Control Workshop**

*Description:* The Local Programs Workshop provided training for local governments that have ordinance delegation and enforces the North Carolina Sedimentation Pollution Control Act. The training provided local programs an opportunity to be updated on the most current erosion and sedimentation control research and to get together with other local programs and exchange sedimentation and erosion control ideas and practices utilized at the local level. This training is helpful for landscape architects that may work for a local government that has an erosion and sedimentation control program.

*Attendance:* 110

**February 6, 2012 NCWRA Seminar “A Fundamental Change in Managing our Community Water Infrastructure”**

*Description:* In recent years many experts and practitioners have come to the conclusion that we must fundamentally change the way we conduct business with regard to our water, wastewater and stormwater infrastructure and operations if we are to successfully overcome the many challenges that our communities are facing or will likely face in this 21st Century. Some of the greater challenges include aging infrastructure and the gap in our financial resources to maintain properly or replace it, increases in impaired waters in our communities that drive regulatory responses, impacts of changing patterns in drought and wet weather, the need to reduce energy consumption for water-related infrastructure and more. Mr. Trevor Clements of Tetra Tech, Inc. discussed research on defining a new paradigm for water management sponsored by the Water Environment Research Foundation and the Electric Power Research Institute.

*Attendance:* 77

<b>Student Support</b>					
<b>Category</b>	<b>Section 104 Base Grant</b>	<b>Section 104 NCGP Award</b>	<b>NIWR-USGS Internship</b>	<b>Supplemental Awards</b>	<b>Total</b>
<b>Undergraduate</b>	7	0	0	0	7
<b>Masters</b>	3	0	0	0	3
<b>Ph.D.</b>	3	0	1	0	4
<b>Post-Doc.</b>	1	0	0	0	1
<b>Total</b>	14	0	1	0	15

# Notable Awards and Achievements

## 1. Dr. Sankar Arumugam's Research Nominated for NIWR Impact Award

In response to the call for nominations for the NIWR Impact Awards, the North Carolina Water Resources Research Institute submitted a nomination for a project funded by Dr. Sankar Arumugam, Department of Civil, Construction, and Environmental Engineering at N.C. State University, entitled "Improved Water Management Strategies for the Neuse Basin Utilizing Climate Information Based Probabilistic Streamflow Forecasts." This project was selected by NIWR's southeast regional winner as having the greatest regional impact, and was presented part of a panel session at the 2012 NIWR meeting in Washington, DC.

This work has great significance for central North Carolina, a rapidly urbanizing area experiencing strong growth in water demand (about 60% over the past 15 years). The region has experienced frequent and severe droughts (e.g., 2002, 2005, 2007), and the principal water supplies (mainly Falls Lake and Jordan Lake) are, like many others in the Southeast and nation, under great stress. The aim of the research is to allow water system managers to use "season ahead" streamflow forecasts based on climate information to evaluate various water restriction levels and make sound decisions on restrictions for the coming months, to better ensure the security of supplies.

When fully implemented, this approach will help systems store additional water during the summer by choosing water restriction levels appropriate to projected drought severity. The study analyzed the utility of this measure by revisiting the last 15 years of data on summer reservoir operations, to understand what could have been done differently using the forecasts available at that time. It clearly showed that the reservoir storage improved significantly if restrictions were enforced based on the projected target storage conditions during July. Results from this work have appeared in *Water Resources Research* (in a paper on forecasting inflows) and in the *Journal of Water Resources Planning and Management* (in a paper on reservoir management).

The system could be fully operational within about 3 years. Subsequent research based on this initial study has developed a real time inflow forecasting portal ([http://www.nc\\_climate.ncsu.edu/inflowforecast](http://www.nc_climate.ncsu.edu/inflowforecast)) for four major systems in the area. Currently, a two year study to convert these streamflow forecasts into experimental storage forecasts is being considered for likely funding by the NC Urban Water Consortium (NCUWC), so that its member municipalities and others can visualize improved storage conditions in the inflow forecasting portal by specifying appropriate restriction levels based on streamflow forecasts.

WRI is confident that improvements in water supply will actually occur through this research, given that the initial project and currently pending proposal for improvements (mentioned above) are strongly supported by local municipal water managers in the region who interact through the NC UWC, and given that the portal is already on line for use. Also, Dr. Arumugam is now working on research projects funded by NSF and NASA to improve the skill of the streamflow forecasts by incorporating remote sensing information and multimodel climate forecasts.

## 2. NC WRI Director Elected Vice Chair of Sedimentation Control Commission

In May 2011, WRI Director Dr. Michael Voiland was elected to serve as the vice chairman of the North Carolina Sedimentation Control Commission. Voiland had served as a commission member since his appointment as WRI director in 2009. The S.C.C. was created in 1973 to create and administer a program to reduce sedimentation resulting from erosion from land-disturbing activities. For more information about WRI's involvement in state sedimentation and erosion control efforts, please refer to the Information Transfer section of this report to read about the erosion control workshops conducted in partnership with the

NC Department of Environment and Natural Resources.

### 3. NC WRRI Helps Water Auditing and Loss Control Efforts Gain Momentum in the Carolinas

Beginning in June 2011, WRRI fostered partnerships between Duke University's Nicholas Institute for Environmental Policy Solutions, the State Water Infrastructure Commission, and an NC-based firm, Cavanaugh & Associates, to pursue training efforts related to water auditing and loss control, a field of growing importance and technological advances aimed at more efficient and cost-savvy management of our nation's water resources. NC WRRI co-sponsored three training workshops (see Information Transfer section of this report for more details) during the project year. The information was so needed, the speakers so dynamic, and the topic so timely that organizations and state government staff in neighboring South Carolina tuned in to the North Carolina efforts. Subsequently, the South Carolina Water Resources Center (South Carolina's USGS-supported WRRI) engaged the NC WRRI to assist with planning and implementation of a similar training effort in Columbia, SC. The South Carolina replication was also a resounding success and led to demands for additional trainings similar to the follow up workshops conducted in NC. We expect that water auditing and loss control will continue to be a priority for the region, and that a continued partnership between the Water Institutes in the Carolinas, and other water audit experts such as Cavanaugh & Associates, will advance the knowledge and adoption of best practices related to this topic.

### 4. Student Supported By USGS Funding Wins Award

In FY 2010, initial federal funding began for a project by researcher Dr. Francis de los Reyes of NC State University entitled "Fate of Fats, Oils, and Grease (FOG) Deposit Forming Precursors in Sewer Systems" (project number 2010NC148B). NC WRRI continued to fund additional components of this research in subsequent years. The NCSU Ph.D. student working on the project, Ms. Xia He, recently completed her Ph.D. and received the inaugural W. Eckenfelder Award for Graduate Research, from the American Academy of Environmental Engineers.



## Publications from Prior Years

1. 2010NC147B ("Microbial Contaminants Associated with Urbanization of a Drinking Water Reservoir") - Other Publications - Wang, AT (2011). Influence of land use and storm events on dissolved organic matter quantity and quality in the Jordan Lake watershed. MSPH technical report. University of North Carolina, Chapel Hill.
2. 2010NC147B ("Microbial Contaminants Associated with Urbanization of a Drinking Water Reservoir") - Dissertations - Rowny, Jakob G. (2011). Characterization of nonpoint source microbial contamination in an urbanizing watershed serving as a municipal water supply. MS thesis. University of North Carolina, Chapel Hill.
3. 2010NC147B ("Microbial Contaminants Associated with Urbanization of a Drinking Water Reservoir") - Water Resources Research Institute Reports - Stewart, Jill, Jakob G. Rowny, and Jennifer G. Shields, 2011, Microbial contaminants associated with urbanization of a drinking water reservoir, North Carolina Water Resources Research Institute, NC State University, Raleigh, NC, UNC-WRRI-403, 67 pp
4. 2010NC145B ("Improved Statewide Soil Moisture Estimation for Hydrologic Assessment and Forecasting") - Dissertations - Pan, W. 2010. Soil Moisture Characterization with North Carolina Environment and Climate Observing Network. M.S. Thesis, Department of Soil Science, North Carolina State University.
5. 2010NC148B ("Fate of Fats, Oils, and Grease (FOG) Deposit Forming Precursors in Sewer Systems") - Water Resources Research Institute Reports - de los Reyes, Francis and Joel J. Ducoste, 2011, Factors affecting the formation of fats, oils, and grease deposits in sewer systems; and fate of FOG deposit forming precursors in sewer systems, North Carolina Water Resources Research Institute, NC State University, Raleigh, NC, UNC-WRRI-404, 50 pp
6. 2010NC148B ("Fate of Fats, Oils, and Grease (FOG) Deposit Forming Precursors in Sewer Systems") - Articles in Refereed Scientific Journals - He, X., M. Iasmin, L. Dean, S. Lappi, J. J. Ducoste and F. L. de los Reyes III (2011). Evidence for How Fat, Oil, and Grease (FOG) Deposits Form in Sewer Lines. Environmental Science and Technology, 45(10): 4385-4391.
7. 2010NC148B ("Fate of Fats, Oils, and Grease (FOG) Deposit Forming Precursors in Sewer Systems") - Dissertations - He, X. Fats, Oils, and Grease (FOG) Deposit Formation: Characterization of Grease Interceptors and Elucidation of Formation Mechanisms (2011) PhD Dissertation, North Carolina State University, Raleigh, NC.
8. 2010NC147B ("Microbial Contaminants Associated with Urbanization of a Drinking Water Reservoir") - Dissertations - Shields, JG (2012). Utilization of microbial source-tracking markers to inform targeted remediation and predict potential pathogens in the Cape Fear Watershed. Dissertation. University of North Carolina. Chapel Hill, NC.